APPLICATION OF PULVERIZED FUEL
FOR MARINE BOILERS.

By Yasushi Taji, Member.

Abstract.

General remarks are given regarding the flame length, burners and the safety of pulverized fuel burning. The relative advantage of the unit and central system are discussed. Various designs including the Gasified Fuel system, Clarke, Chapman's system, Brand system, installation on the "Mercer" etc. are described. A certain criticism of various pulverized fuel burning systems and the author's personal desires are expressed.

I. General Remarks.

The application of pulverized fuel for land purposes has been well advanced and various systems have been introduced both in America and Europe, while the experience for marine boilers is still so meagre. Some experiments were carried out on the United States patrol vessel "Gem" and on an Australian ship "Sealark", and very recently on the S.S. "Mercer" of the United States Shipping Board. Except in the case of the "Mercer", the fuel was pulverized on shore and charged to the ship's bunkers through ducts. A unit system has been installed and experimented on the S.S. "Mercer" and full details were published in a paper read at the thirty-fifth general meeting of the Society of Naval Architects and Marine Engineers, New York, Nov., 11, 1927.

The question of the application of pulverized fuel for marine purposes has, however, greatly attracted the attention of marine engineers during the past few years, and now many firms are carrying on various experiments.

Much argument has also been introduced on steam turbines versus Diesel engines. Some engineers consider high pressure steam turbines with powdered fuel burning boilers will be the only solution of the problem from the economical standpoint.

It is generally thought that the extreme long length of flame usually associated with the pulverized fuel firing, and consequently the large combustion chambers required for the efficient combustion of powdered fuel will hinder its practical adoption on board ships. This difficulty, however, has been tackled from various points. English engineers have successfully carried out experiments by attaching an external combustion chamber to the boiler front, although there are certain differences in accordance with various designers, such as "Gasified Fuel", "Clarke, Chapman", "Brand" etc. Experiments were also carried out by Prof. Chapman of the
Massachusetts Institute of Technology, with a type of powdered coal firing intended to give efficient combustion with reasonably short length of flame, and hence with boilers of moderate overall dimensions. So far as experiments are concerned, the new burners give a flame length of 6 to 10 feet, while the usual old type has a length of over 15 feet.

In S.S. “Mercer”, special burners designed by the Peabody Engineering Co. were used and it is believed considerably short flames were produced by making a turbulent motion of the powdered fuel. Although there are some difference in the design, it is reported that a short flame has been also obtained in Clarke, Chapman’s burners and Brand burners.

Another solution may be the adoption of special fuels for pulverization, such as “Coalite”, “L. & N.” fuel etc., which are products of the low temperature carbonization and have many advantages such as short flame, easy pulverization, safe storage, low ash content etc. Evidently, these fuels are difficult to obtain in every port, but if the application becomes popular, stores will be established in many ports.

The danger from the spontaneous combustion or explosion and difficulties of storing the powdered fuel have been already well studied by various authorities. It appears to me the general conclusion is that in modern appliances there is practically no danger. In a large storage, incombustible gases may be used, for instance in Brand system the cooled flue gas was introduced from the funnel. It is natural that the smaller storage is the safer; on this ground the unit system will be more suitable for marine purposes.

The spontaneous combustion with coal dust is only possible when coal is aerated and not when it settles. When the latter condition prevails the coal packs closely, and the interstices in which air with its oxygen can lodge are infinitesimal. In consequence, when a fire starts it soon burns itself out without danger.

Special Report No. 1 of the Fuel Research Board of the United Kingdom dealt with several problems such as,

1. Danger from explosive mixtures of coal dust and air;
2. Settling down and caking in the supply tanks or bunkers;
3. Danger from spontaneous combustion in the tanks or bunkers.

These objections were so clearly answered in the report, that no coal dust can escape into atmosphere by the method intended to be employed and also caking or settling down in bunkers offers no impediment worth consideration, for it may be easily fluffed up. There is no danger whatever from spontaneous combustion, for it is im-
possible for coal to burn without an ample quantity of air, but such conditions are not obtainable in a closed steel cylinder.

As regards the pulverization on shore or on board ships, it appears to me that for small vessels the charging and storage of powdered coal from shore will not cause much difficulty as experienced in the "Sealark", but for large ships there will be great trouble regarding its supply and storage.

The relative advantage of the unit system and the central system are still under discussion even on land power installations. For marine purposes, the unit system will be much simpler than the other as each machine combines the functions of pulverizers, transporters and fans. Usually dryers are not necessary in the unit system unless extremely wet coals have to be used. Even when very wet coals are to be used, a cheap steam dryer may be adopted instead of the expensive and bulky dryer. Further, in the unit system, handling is more economical and each boiler is independent, so that they are much safer from breakdown. These are very important factors in the marine installation.

Consequently, I believe the future development of pulverized fuel for marine purposes should follow the reliable unit system, except in the case of small vessels serving in a limited coast area.

Refering pulverizers, there are two types i.e. a low speed type where the coal is pulverized by a large number of iron balls or rollers and a high speed type which uses rotating paddles or "beater". The latter type is lighter and more compact and will probably be the favourite for the use on board ships, although on the "Mercer" the former type has been adopted.

The great economy of the powdered fuel burning is that extremely low grade coals such as coal mine slacks etc. can easily be utilized for the steam generation, and there are records of applying coals with 35% of ash. It is reported that the Nechells Power Station in Birmingham used coal having 20% ash, price delivered at 7 shillings per ton, with calorific value of 9,000 B.T.U.

The power required for pulverizing one ton of coal varies a little as to the nature of the coal and the moisture contents, but taking a maximum figure with coal containing 15% moisture, it will be about 13 to 14 K.Ws. per ton of coal. A certain authority gives 1\frac{1}{4} to 2\frac{1}{2} % of the price of coal as the cost of pulverization.

II Some Designs of Pulverized Fuel burning Marine Boiler Plants.

(A) Gasified Fuel System.
In this system, an external combustion chamber named "Pregasifier" is fitted to each furnace. Special precaution is taken to produce a turbulent motion of the powdered fuel in the pregasifying chambers where carbon mono-oxide gas is produced which will be converted into carbon di-oxide in the furnaces after combustion. The construction is shown in Plate I.

The principle of this system and results of experiments carried out in a Paxman boiler are described in "The Engineer" of the 3rd. Sept., 1926.

The present proposed design has been carried out on assumption that a N.Y.K. boat of H. Class is to be converted into a powdered fuel burning vessel under the following condition:

- S.H.P. on service .............................................. 8,000
- Steam consumption including auxiliaries in lbs. per hour ........................................ 92,000
- Boiler pressure in gauge ........................................ 280 lbs. per sq. in.
- Temperature .................................................. 700 deg. F.
- Quality of coal to be burnt:
  - Volatile matter .............................................. 36 %
  - Fixed carbon ................................................. 49 %
  - Ash ............................................................. 8 %
  - Moisture ...................................................... 6 %
  - Calorific value ................................................ 12,000 B.T.U.

In the proposed design as shown in Plate II, careful consideration is given to the question of the pulverizing machinery, and this arrangement is advocating the unit system, providing one self-contained pulverizing and drying unit for each boiler, while this appears at first sight to entail unnecessary duplication of machinery.

The importance of the freedom from breakdown and entire elimination of the storage of coal in powdered form are taken into consideration.

In the arrangement, the coal is pulverized only as it is used, and the length of piping which conveys coal dust is made as short as possible. The only storage required is of the coal in the new state, and conveyers and elevators for this should be reliable in continuous service, and can moreover be made entirely dust-tight in operation.

Some consideration will have to be given to the construction of the coal bunkers to provide for the gravitation of coal to the inlet of the elevators, and this is indicated in the cross bunker. By the provision of six boilers instead of seven as installed in the original plans, the boiler room can be shortened and the space saved may be added to the cross bunker space if necessary. The provision of a sloping bottom to the side bunkers does not appear very practicable, and this bunker space might be conveniently provided for elsewhere.

The elevators and conveyers shown supply coal direct from the bunker to the
pulverizers; where it is likely that coal of larger size than one inch cube will be used it would be necessary to provide a coal crusher, which would preferably be situated between the outlet from the top of the elevators and the screw conveyor.

Each of the pulverizers shown has a maximum rate of capacity of 2,500 lbs. of coal per hour, and the normal consumption of each boiler is estimated to be about one ton of coal per hour.

For the sake of simplicity, natural draught conditions are assumed, with which the boilers should each produce about 18,000 lbs. of steam per hour normally, going over 1,000,000 lbs. per hour total, so that five boilers will probably suffice on many occasions. In cases where the space occupied by the boilers is more important, it may be possible to use forced draught with a higher rate of evaporation, and the number of boilers possibly reduced.

The boilers shown are the ordinary Scotch marine return tube type without any modification except for the provision of connections through the back water space for the pneumatic extraction of ash dust from the combustion chambers. This dust can be very satisfactorily removed by a steam jet device which will periodically discharge directly overboard.

The ash which is periodically removed from the doors in the front of the pre-gasifiers is generally in the form of clinker, and will be removed by the usual ash hoist.

The design having been carried out without material alteration in the boilers proper, the extra equipment for the pulverized fuel burning will be approximately as follows:

18—Pregasifying chambers with refractory lining and secondary air jacket, fitted with sliding ash door and opening gear, inlet fitting with damper, secondary air control shutters, etc. Each pregasifier will be capable of dealing with up to 750 lbs. of the specified coal per hour.

18—sets of refractory linings for the boiler furnaces with jointing material.

6—35 to 40 H.P. motors and starters assuming 220 volts D.C. directly coupled to the pulverizers.

3—raw coal service bins and two basket elevators; capacity will be up to six tons per hour.

As regards pulverizers, "Forplex" type as fitted in the experimental boiler is adopted which is capable of pulverizing up to one ton of coal per hour with hot air drying attachment up to 14% of free moisture.
(B) Clarke, Chapman's System.

(1) Water-tube Boilers.

Messrs. Clarke, Chapman & Co., Ltd. of Gateshead-on-Tyne, England have designs of two types of pulverized fuel plants for marine purposes. One is Water-tube type and the other is Scotch boilers with extended furnace.

The latter has been already tested and the former is still only a proposed design, but they have great confidence in their ultimate success in view of their extensive experience acquired from the pulverized fuel burning plant of Woodeson's patent water tube boiler in their factory.

The proposed design is shown in Plate III. The boilers consist of one steam drum at the top and one mud drum at the bottom connected by steam generating tubes. Not only these tubes, but water side walls consisting of numerous steel tubes are arranged and special precaution is taken for the efficient circulation of the boiler water. The construction resembles in some way a radiant water tube boiler, yet the usual practice of powdered fuel burning is adopted under the principle of the unit system. The construction and handling appear to me much simpler than radiant boilers, while the performance will only be determined after actual steam tests.

The boilers were designed in two capacities, one at 250 lbs. pressure with heating surface 3,000 sq. ft. at boiler, 750 sq. ft. at water cooled wall, making a total surface of 3,750 sq. ft.; and the other at 500 lbs. pressure with boiler heating surface of 2,460 sq. ft. and water cooled walls of 740 sq. ft., making 3,200 sq. ft. in total.

Two single ended W. T. boilers are arranged in beam with athwartship feeding of the fuel, and for the vessel quoted four boilers with one or two auxiliary boilers would be installed, while each main boiler will have own turbo-pulverizing installation and the auxiliary boilers are fed from these main turbo-pulverizers.

The raw coal will be conveniently stored in upper bunkers, but if preferable would be kept in cross-bunkers when elevators are used.

The supply of air is effected by two passages. The primary air is drawn from the combustion chambers through a series of air ducts directly into the pulverizer. By this primary air the coal is delivered to the burners and at the same time the heat dries up the moisture in the coal to enable the pulverizer to deal with it. The temperature of air in the pulverizer seldom exceeds 160 deg. F., as the heat entering is immediately reduced in temperature by coming in contact with the moisture of coal. The secondary air comes through air heaters attached to the funnel bottom heated by the flue gas and enters to the register of the fuel burners, delivered by a fan conve-
niently placed in the engine room to suit the arrangement. As prescribed, this system being similar to the practice of oil fuel burning, comparatively short flames will be expected.

Ashes will be withdrawn through openings at the bottom of the combustion chambers or steam ash ejectors will also be applicable.

(2) Marine Cylindrical Return Tube Boilers.

This system somewhat resembles the Brand system except in the construction of external combustion chambers, burners and pulverizing method; this system is unit pulverizing, while the Brand system is ready pulverizing.

The Clarke, Chapman's experimental boiler has a double furnace each 2 ft. 10 ins. internal diameter, the boiler itself is 10 ft. 3 ins. external diameter and 9 ft. long. The length of the horizontal return tubes is only 5 ft. 5 ins. which will not be enough to have the best opportunity for obtaining real good results. They are, however, burning coal of very poor nature as well as the residual fuel obtained from "L. and N." process of low temperature distillation and results obtained have been quite favourable.

Details having been quoted in Eng.-Captain Brand's paper read at the Summer meeting of the I.N.A. last year, further remarks will not be necessary.

(C) Brand System.

The Brand system was installed and experimented on the Australian ship "Sealark" and its detail has been fully described in papers read by Eng.-Captain Brand before the Sydney Division of the Institution of Engineers, Australia, on June 14th, 1923, and also before the I.N.A. July 12th, 1927.

In the "Sealark", coal was pulverized on shore and powdered coal was charged to the ship's bunkers by pipes. The boiler upon which the experiments were carried out was a single-ended return-tube boiler 11 ft. in diameter by 9 ft. 3 ins. long and fitted with corrugated furnaces. The heating surface was 980 sq. ft. and two combustion chambers volume 200 cb. ft. An external chamber of a special form was built on to the boiler front while the air box, air cone and burner were fitted on the top of the chamber. The main air supply was taken from a Howden air heater contained in the smoke-box and the coal was fed to the ready-use bin by pipes from the bunker. A fan was situated above the ready-use bin and discharged the coal dust to the latter through a cyclone separator.

In the process of pulverization coal is aerated, but during charging in the bunkers the vibration of the vessel de-aerates the fuel and hence in the experiments carried
out in Australia, fluffing pipes were introduced just above the bunker and in the ready-use bin, so as to maintain aeration by the injection of inert gas at a pressure slightly higher than that of the head of the powdered fuel.

To determine the amount of fuel in the ready-use bin, two methods were used; one by a glass sounding tube, and other by a rectangular projection fitted with a protected triple-glass window running the depth of the bin, and being illuminated on one side by an electric lamp.

The possibility of an explosion occurring in the bunker or the supply pipes to the ready-use bin was avoided by passing inert funnel gas along the bunkering pipe.

A screw feeder rotates in a casing secured to the bottom of the ready-use bin, where the primary air enters and feeds powdered coal to the down pipe. The mixing of the fuel is effected by a so-called "Carburettor" fitted with a wire gauze diaphragm and the passage of fuel and air through this causes intimate mixing.

The end of the mixing pipe slips over the burner pipe, and can be adjusted to ensure the firing just at the point of admission of the secondary air. The secondary air from either a closed stokehold or a Howden heater is introduced into an air box controlled by flaps. This air passes through a ring with curved vanes in order to produce a turbulent motion at the entrance to the combustion chamber.

(D) Installation on S.S. "Mercer".

This is a unit system installed on the ship after exhaustive research by the United States Shipping Board.

As shown in Plate V, the coal is taken from bunkers by conveyers and is crushed by a coal crusher to a suitable size for pulverizing. The pulverizer is of the Kennedy air-swept ball mill type which delivers the powdered coal to distributors and hence to burners. The burners are of the Peabody combined fuel-oil and pulverized coal type ingeniously designed to produce turbulent motion of fuel and air at the entrance of the furnaces.

After crossing the Atlantic, the results were recognized as quite successful.

Full details having been published in a paper read at the meeting of the Society of Naval Architects and Marine Engineers, New York, Nov. 11, 1927 and also in "Engineering" of Dec. 16, 1927 etc., further remarks will not be necessary.

(E) Other Designs.

Various firms in Europe and America are advocating water-tube boilers for the pulverized fuel burning on board ships. Some are considering the modification of ordinary types of marine water-tube boilers to suit the purpose, while others are pro-
posing radiant water-tube boilers. Actual tests with a standard Babcock and Wilcox water-tube boiler has been already carried out in America (see Mr. Stillman’s paper read before the Society of Naval Architects and Marine Engineers, New York, Nov. 11, 1927).

In new vessels, the relative advantage of using special water-tube boilers or ordinary Scotch boilers will be still an unsolved problem, particularly from the economical consideration. It is, however, absolutely necessary to adopt specially designed straight water-tube boilers, in case of using the high pressure steam.

III. Conclusion.

As regards the comparative advantages of each system, it is difficult to decide this at the present stage of development, although it is reported that the “Mercer”’s results have been quite satisfactory. The question of burners is very important, whether the Peabody’s burners act exactly as oil fuel burners or not may be still doubtful, as Brand’s or Clarke, Chapman’s burners stand more or less on a similar principle, yet they prefer to have external extension of the furnace. The beauty of the Gasified Fuel System is the elimination of the complicated fuel burner and the simplicity of construction.

The complication of the piping of the “Mercer” installation will not be very desirable, as the distributors must have found it difficult to give uniform firing in each furnace.

To avoid the complication of piping and to ensure the uniform distribution of fuel, it will be recommendable to arrange one pulverizer to each boiler, as in the Gasified system or in the Clarke, Chapman’s system. This will surely augment the reliability of each boiler.

Whatever system may be used, it is absolutely certain that the pulverized fuel burning is much more advantageous than the old hand-firing process.

Whatever system may be considered, the boiler efficiency under the pulverized fuel burning has shown from 67.4 % to 77.06 %, while hand firing boilers have usually from 60 % to 65 % of efficiency.

In experiences on land as well as on sea, the advantages of burning coal in a pulverized form have been definitely recognised, as the heat values of coal can be utilised to a far higher degree. The advantages include the economy in fuel consumption, the efficient use of almost any grade of coal, danger in suitably designed plants is minimized, easy handling of the slug or dust resulting from the ash in coals,
great saving in labour, smokeless combustion etc.

In view of the existing status of steamships, it appears to me that the development of the powdered fuel burning in ordinary marine return-tube boilers with or without external combustion chambers and with the unit system of pulverization will be preferable.

I am not venturing to make a comparison between Diesel engined ships and pulverized fuel burning ships, as each stands upon its own merit.

If the vessel visits a port where oil fuel is cheap, it will be certainly recommendable to use oil, either in the form of fuel in Boilers or Diesel set. In a country like ours, where oil is very scarce, the question of the pulverized fuel burning is extremely important from an economic standpoint.

It is to be hoped that either the Government or private firms will make further endeavour to research upon the foregoing subject and carry out actual experiments far beyond anything that has yet been done in America, and thereby open wide the final door of success to this interesting and decidedly important investigation.

討 論

○ 會長（今岡純一郎君） 只今の御講演に対する御討論なり仰賀間なりありましたる御達べを願ひます。

○ 光永篤三君 「マーラーのレポートに就て仰伺いたいと思ひます。此の前刷には「アーシュ、コンテント」35％位の石炭でも使へども云ふことが書いてあります。是れに就いては如何でありますでしょうか。

○ 田路勝君 「マーラー」で35％迄の石炭を使んだと云ふのでありますか。35％位の石炭を陸上の「バルツライフスト、フューエル、バーニング、ボイラ」で使った記録があると云ふことです。別に大した不都合が無かった様に思はれます。

○ 光永篤三君 火焰温度が途程高くなるので、石炭によっては普通以上に「クリンカー」が多くなると思はれますが、共「クリンカー」の処置はどうするのでさせるか、夫れによって「ボイラ、エフイシェンシー」は非常に宜しい時と居る悪い時である譲で、非常にうまく行く時は「オイル、バーニング」に近いものでせようが、「ヒーティング、サーフェース」が著しく汚れる場合が想像されます。「ニューヨーク」と「ロタブル」両者2週間以上の航海で、果てが「トラブル」の一つではなかっただか、夫れに対する処置は何なうて居ると云ふことは判りませぬが、さら云ふことまで判りましらぬ教へて戴きたい。

○ 田路勝君 「バルツライフスト、フューエル」を使用する際、普通航路の様に「クリンカー」で非常に困ったと云ふことは聞きません。是は石炭が非常に細かい粉末にて居るのと燃焼温度の非常に高
い故でしょう。夫に大抵「ピチューミナス、コール」類を使用せず寧ろ「リグナイト」類を多く使用する點もありましょう。本船の記録に依れば「ファーネス」及び「ア.プステーキス」は約五千哩走つ後一度掃除しただけで「オイル バーニング」と同様でげれて居なかったそうです。「マーサー」の実験は自分が英 国出発後の事でありまして実際にに行って聴き正したものは無く、其後の発表された報告記事及び「ペーパー」等に依ったものであります。「マーサー」の設備は米国船船院が陸上で「スコッチ、ボイラ ー」を「バルヴァライズド、フェーユル、バーニング」に改造して実験した成績より、直ちに「マーサー」営繕 及び気動室設備を改造して實用に供したもので、且つ大西洋横断航行成績が外見良好なため、此船 が「ニューヨーク」に帰港後他の米国船船院所有の船数隻を「バルヴァライズド、フェーユル」燃焼船に改 造を行ふと云ふので、「マーサー」の實際航行成績の詳細は未だ発表されて居ません。然し御質問の様 な「クリンカー」に苦しまれたと云ふ様な事は聞いて居ません。

○光永藤三郎　どう云ふ分析の石炭を使ったかと云ふことは分りませぬか。
○田路坦君　夫は判って居りませぬ。
○光永藤三郎　石炭の名稱は･･･。
○田路坦君　陸上で「スコッチ、ボイラーテ」で試験した時は気動設備も米国船船院の人々のみならす方々の専門の「エンジニア」が共力して居り、共試験用の石炭も炭坑会社が特性にて寄附してやった様 な大抵共種類は「ベンシルヴァニア」の「-nineチー・グローベッシュ」及「セミピチューミナス、コール」で ありますから、「マーサー」の試験の場合もほぼ同様な種類の石炭を使用したことだろうと思ひます。
○会長（今岡純一郎君）　外にはありませぬか。夫では田路君は歓迎会で用ひて居らが吾々から見 ると専門外である外國の船に使って居る粉炭燃料を御調覈になつたものを御発表させられ、本度会は此 重要なる問題に就て注意を喚起せられたことは頗る機宜に適したことで深く御禮を申上げます。此問題 は矢張り日本の陣と海との研究の題目となると思ひます。誠に有益な御意見を御発表になったこと に封し諸君と共に拍手を以て御禮を申上げます。
（一同拍手）
PROPOSED ARRANGEMENT OF TWO CLARKE CHAPMAN MARINE TYPE WATER TUBE BOILERS.

WOODS & SON'S PATENT

FITTED WITH AIR HEATERS & FIRED WITH PRESSURIZED FUEL BY THE CLARKE CHAPMAN TUBRO PULVERIZERS.

750 LBS. PRESSURE

HEATING SURFACE: BOILER 3000 SQ. FT.
WATER COOLED WALLS 750 SQ. FT.
TOTAL 3750 SQ. FT.

500 LBS. PRESSURE

HEATING SURFACE: BOILER 2400 SQ. FT.
WATER COOLED WALLS 740 SQ. FT.
TOTAL 3140 SQ. FT.

SCALE 1/4 = 1 FOOT
Plate V.

Marine Boiler Fitted with Powdered Fuel
Unit System
Clarke Chapman Patent
Plate VI.

1, Howden air heater; 2, Air main; 3, Dust separator from bunkers; 4, Ready use bin; 5, Primary air; 6, Fluffing air to conveyor; 7, Secondary air; 8, Drag conveyor; 9, Feeder; 10, Mixer; 11, Variable-speed gear; 12, Air cone; 13, Secondary air box; 14, Opposing air; 15, Bridge; 16, Slag door.