

MARINE COMBUSTION PRACTICE

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PART I

COMBUSTION EQUIPMENT
FOR BOILERS

JOSEPH FLACK
C. Eng., M.I.Mech.E., A.M.I.Mar.E.

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CHAPTER 1

SOLID FUEL

SOLID fuel is no longer regarded as a commercial marine fuel. However, since it is still used to a limited extent, it is worthwhile appraising its value and properties for comparison with liquid petroleum fuels.

The solid fuel used for marine purposes is generally confined to coal in its more mature form and excludes peats and lignites.

The term “coal” is applied to deposits which lie in seams at or near the earth’s surface and have been produced by the compression and heating of decayed plant materials accumulated millions of years ago.

Coal varies in its properties and nature throughout the world usually in accordance with the nature of the original vegetable matter, the extent of its bacterial decay, the amount of earthen matter present and the effect of heat, pressure and disturbance during its formation.

A. COAL CLASSIFICATION

There is no easy method of classifying or grading of coal and no universal standard. Most systems of classification are based upon some characteristic property of the coal series that changes uniformly and progressively with increase in “maturity” or “rank” as the series is ascended. Classifications are usually based on either “Ultimate analysis” or “Proximate analysis” (see Table I.1).

1. *Ultimate Analysis*

This is an analysis in terms of the percentages by weight of the elements present, viz. carbon, hydrogen, oxygen, nitrogen and sulphur.

2. *Proximate Analysis*

This is an analysis in terms of the percentage of moisture, volatile matter, ash, fixed carbon and sulphur; plus the calorific value.

B. PROPERTIES OF COAL AFFECTING COMBUSTION AND COMBUSTION EQUIPMENT DESIGN

The carbon, hydrogen and to a minor extent the sulphur contents of the coal determine the possible heat release but the rate and method of burning is very largely dependent on the volatile, moisture and ash contents and the caking and coking properties of the fuel. Reference to Table I.2 gives some idea of the possible variables in world coal supplies.

TABLE I.1. AVERAGE PROPERTIES OF COALS (Extract from Spiers, *Technical Data on Fuel*)

		Lignite	Bituminous coals				Semi-bituminous coals	Semi-anthracite	Anthracite
			I	II	III	IV			
Ultimate	C	70.0	77.0	82.0	86.0	88.0	90.5	93.0	94.0
Analysis	H	5.0	5.5	6.0	5.5	5.0	4.5	3.5	3.0
(Dry ash-free	N + S	2.0	2.5	2.5	2.5	2.5	2.0	1.5	1.5
fuel)	O	23.0	15.0	9.5	6.0	4.5	3.0	2.0	1.5
Proximate	Volatiles	50.0	40.0	35.0	30.0	25.0	18.0	10.0	4.0
Analysis	Fixed carbon	45.0	55.0	60.0	65.0	70.0	78.0	86.0	93.0
(Dry fuel)	Ash	5.0	5.0	5.0	5.0	5.0	4.0	4.0	3.0
B.t.u./lb	{ C.V. gross	11,520	12,960	14,940	15,480	15,480	15,750	15,480	15,480
	{ C.V. net	11,052	12,438	14,958	14,202	15,012	15,318	15,156	15,192
Moisture content		50.0	10.0	5.0	2.0	2.0	1.0	1.0	1.0

This table indicates typical compositions of coals falling into each of the classes included in the classification. It should be understood that wide variations are encountered among coals entered in each group.

TABLE I.2. CONSTITUENT VARIATION IN WORLD COAL SUPPLIES

Constituent	Percentage variation
Carbon	56-91
Hydrogen	3-6
Oxygen	2-32
Sulphur	0.5-2.5
Ash	2-15
Moisture	0.6-16
Volatiles	4.5-45

1. Volatile Matter

This consists of the inherent moisture, gas and tar extruded or given off during the initial decomposition of the coal on being heated, bearing in mind that coal does not burst into instantaneous combustion in its entirety.

In the design of a suitable air register for use with coal-burning equipment, special provision is made for the supply of a secondary air stream of sufficient quantity and turbulence to complete the combustion of the volatile content over the firebed (see Figs. I. 1, I., 2).

The majority of steam-raising plants are usually supplied with coal containing from 20% to 30% volatile matter. These coals burn with a short to medium length flame and can be consumed at normal rates with natural draught or at high rates with forced draught and mechanical firing. Coals containing from 14% to 20% volatiles are termed semi-bituminous and although relatively expensive can sometimes work out to be the most economical especially when high rates of firing are required. Coals of this class can often be consumed without difficulty utilizing natural draught but for higher rates of consumption some form of mechanical draught becomes necessary.

The most valuable coals used for steam raising are the "free-burning" coals and are those in the semi-anthracite and anthracite classes. These fuels are low in volatiles, 8–14 %, and burn smokelessly with very little secondary air. Again for high rates of firing, mechanical draught is essential.

2. Moisture Content

All grades of fuel contain natural or inherent and free moisture. The latter is acquired during the washing process, exposure to atmospheric conditions or is added prior to admission into the furnace. Although the loss of heat during combustion due to the presence of moisture is not appreciable (a fuel with a C.V. of 12,500 B.t.u./lb and a boiler exhaust gas temperature of 450°F would only result in a loss of 123 B.t.u./lb of moisture, or 0.98 % of its thermal capacity), it should be noted that unless care is taken, 1 ton of coal can contain as much as 2 cwt of moisture which is an appreciable item to be paid for at the same price as the actual coal.

Combustion of dry dusty slacks is usually improved by the addition of moisture prior to the fuel being placed onto the fuel bed. The added water tends to hold the particles of coal together during the initial stages of heating while the evaporation of the water helps to make the fuel bed porous, preventing the formation of tarry cokes and allowing the air required for combustion to become more closely associated with the fixed carbon and volatiles. The amount of moisture added can be as much as 6 % of the weight of the coal.

3. Ash Content

There are in effect two ash content figures for coal depending on either the chemist's or engineer's analysis. The chemist's analysis refers to the impurities of solid earthen matter remaining after complete combustion of the carbon, hydrogen and carbo-hydrogen contents. The latter analysis is, however, far more relevant from the ship-owners' point of view since it also includes unburnt "fines" carried through with the ash into the ashpit, i.e. very small dust particles of unburnt coal which mingle with the ash and represent a loss in combustible matter. With respect to the combustion equipment used, the ash fusion temperature is generally the most important factor to be considered (i.e. the temperature at which the ash becomes molten and fuses together into a plastic mass). The fusion temperature varies with the type of soil or earthen matter present within the body of the coal, and may include the constituents silica, alumina, iron oxide, lime, magnesia and small amounts of alkalies all in various proportions (see Table I.3).

TABLE I.3. CONSTITUENT VARIATION IN COAL ASH

Constituent		Percentage variation
Silica	SiO ₂	25–50
Alumina	Al ₂ O ₃	30–40
Ferric oxide	Fe ₂ O ₃	0–30
Lime	CaO	1–10
Magnesium	MgO	0.5–5
Titania	TiO ₂	0–3
Sulphur trioxide	SO ₃	1–2
Alkalies	NaO and K ₂ O	1–6

The highest melting points are obtained when the ash is composed mainly of alumina and silica, but the presence of fluxes, i.e. alkali oxides, lime, magnesia, titania and iron compounds, tends to lower these melting points in accordance with their proportion and quality. In general, the following temperatures apply:

Melting point 1425–1710°C: clinkering troubles absent.

Melting point 1200–1425°C: clinker may form but is not likely to be excessive.

Melting point 1040–1200°C: clinkering troubles excessive, unless adequate precautions are taken.

The ash melting points of most British coals lie between 1050°C and 1350°C, and though there are many notable exceptions, such as the ashes of durains, care is usually required to prevent excessive clinker formation. When the fusion point of the ash is low, clinker is easily formed and tends to fuse onto the firebars preventing the admission of combustion air which reduces the rate of combustion and necessitates frequent fire cleaning or the fitting of special fire grates.

An excessive ash content similarly impedes the air supply, retards combustion, and leads to a considerable loss of heat and fuel particularly when the firing is forced to produce higher rates of heat release.

Ash disposal can often be a source of trouble and expense, e.g. a coal with a 5% ash content consumed at a rate of 10 tons/day, means that 10 cwt of inert material must be removed from the furnaces and disposed outside the stokehold.

4. *Caking Property*

As the name implies, this is the property similar to that obtained in baking a cake when the mixture of constituents is changed from a semi-liquid mass into a more rigid cellular structure, crusting on the surface. What are termed strongly caking coals on being placed on a hot firebed pass through various stages of decomposition.

- (i) At temperatures between 290°C and 450°C caking coals become plastic and “melt” with individual pieces gradually merging into one molten mass.
- (ii) Gases evolved during the plastic stage blow the liquid coal into a froth as they endeavour to escape through the coal bed.
- (iii) As the decomposition proceeds, the mass becomes more and more viscous, “drier”, and eventually rigid, forming a hot coke inside with a black porous crust.

The important factors when dealing with strongly caking coals are usually the allowable depths of the firebed and the amount of raking required to maintain combustion.

Coal is a poor conductor of heat and, when relatively thick fuel beds are used, the various stages of carbonization or decomposition take place in well-defined zones which gradually progress from the hot inner zone outwards. The thin plastic zone, formed with strongly caking coals, acts as a heat barrier resulting in a considerable temperature gradient (there may be a temperature drop of some 250°C across a $\frac{3}{4}$ -in. thickness). As a result of this heat barrier partial insulation of the upper layers from the hot zone can appreciably retard the rate of combustion unless measures are taken to remove or break down the plastic zone and the hard crust which replaces it. Non-caking coals produce no plastic layer on heating and hence the reason for referring to them as “free-burning” coals.

In the classification of coals there is no simple relation between the caking property and the volatile, carbon and hydrogen contents.

C. COMBUSTION OF COAL

The combustion of coal can be considered as taking place in four distinct stages:

- (i) Removal of moisture.
- (ii) Evolution of volatile matter,
- (iii) Ignition and combustion of solid coke.
- (iv) Combustion of volatile matter and combustible gases including carbon monoxide.

When coal is burnt on a grate, the rate of combustion depends on the rate of coal and air supplies and the properties of the coal which control its rate of decomposition. The volatile matter can be burnt at almost explosive rate provided sufficient secondary air is available while the coke residue can be burnt at a rate depending on the amount and pressure of the primary air available and its penetration into the fuel bed.

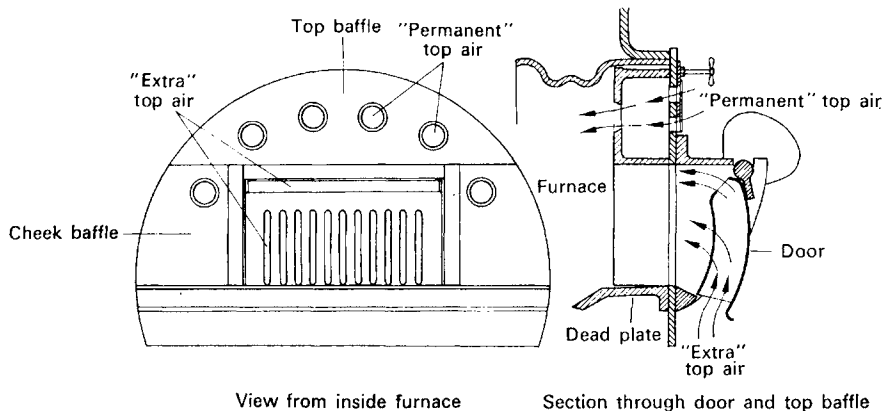


FIG. I.1. Smoke eliminator for natural draught marine boiler.

Thermal decomposition of the coal is relatively slow even at high fuel bed temperatures so that for optimum conditions of combustion, to ensure the intimate association of air and combustible matter in its various decomposed forms it is necessary to create the correct type of bed for each grade of coal.

With land installations, receiving similar grades of coal from the same mines or area, coal burning equipment is fitted to suit. However, with marine installations the situation is far more complicated since it is most impracticable to have boilers fitted with more than one type of air register and firing grate to suit the wide range of fuels likely to be encountered. Firing under these circumstances can be extremely difficult and on occasion virtually impossible.

D. METHODS OF COAL FIRING

In marine installations coal has been mainly fired in combustion chambers fitted with some form of firegrate although certain vessels on definite runs have been successfully adapted to fire powdered or pulverized coal.

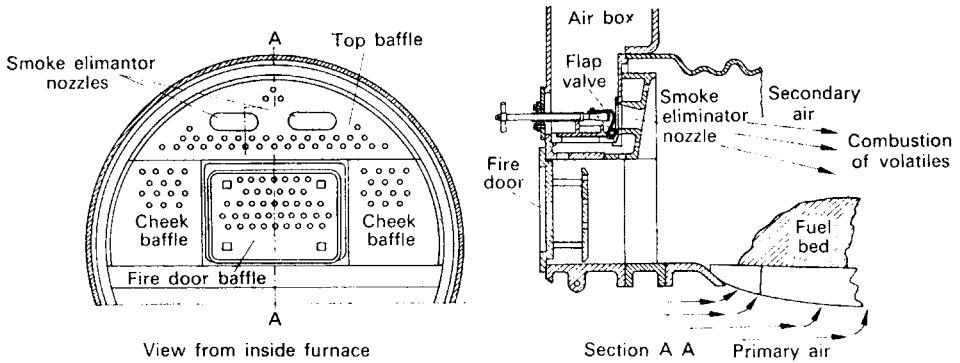
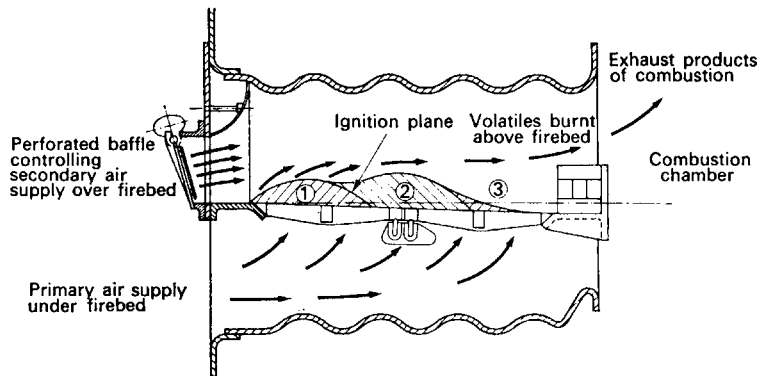


FIG. I.2. Smoke eliminator for forced draught marine boilers.

1. Combustion of Coal on Grates

(a) Coking method

This method relies on the formation of a deep coke bed to promote the stages of combustion. Fresh coal is charged onto the front of the grate and combustion takes place in definite stages as shown in Fig. I.3. The moisture content and volatile matter is driven off



- (1) Distillation Zone—Consists mainly of “green” fuel. Proximity to hot zone (2) helps drive off the moisture and volatile content of the fuel.
- (2) Producer Zone—This is a reducing zone in which CO_2 produced in the lower layers of the incandescent “fixed” or solid carbon bed is reduced to CO during its passage upwards.
- (3) Oxidation Zone—Combustion of the remaining carbon is completed in this zone by an excess supply of air passing unrestricted through a rapidly thinning fuel bed which at the extreme end is reduced to ash and clinker only.

FIG. I.3. Coking method of burning coal.

during the distillation of the coal due to its proximity with the hot coke bed. A combustible gaseous mixture is formed with the volatiles and primary and secondary air which is then ignited and burnt as it passes over the incandescent fuel bed, in particular the thin red hot ash zone at the rear of the grate. Before more coal is added, the coke mass is broken up and pushed towards the rear end of the grate when the process is revitalized by the addition of more coal.