Combustion Equipment

Combustion equipment for

Solid fuels

Liquid fuels

Gaseous fuels
Combustion equipment

Each fuel type has relative advantages and disadvantages. The same is true with regard to firing systems. It is important to have the fuel and the combustion equipment suitable for the intended use.

The choice of appropriate combustion equipment does not depend on considerations relating only to the actual combustion.

Points to consider:

- feeding of the fuel
- feeding of the oxidant
- mixing zone
- ignition zone
- stabilization zone
- exhaust circuits
- safety
- environmental considerations
- costs (purchase, use, maintenance, ...)
- ...
The combustion equipment has (typically):
- combustion chamber (or combustion zone) burner(s)
- auxiliary systems

The type of combustion chamber and burner depend on:
- type of use
- type of fuel
- power
- mixing process
- flame stabilization process
- surrounding, space, acceptable weight,

The auxiliary systems are equally important:
- circuits of:
  - fuel feeding
  - oxidant (and other gas, in some applications) feeding
  - exhaust of gaseous products, ashes, etc,
  - cooling
- fuel separation processes
- control systems
- safety systems
...
Solid fuels feeding system

Solid fuels may be burnt as

- lumps and briquettes (coal, wood, residuals) – fixed grid bed
- particles and sticks (coal, wood, residuals) – fixed or fluidized bed
- pulverized (coal) – (pneumatic burners)

Solid fuels are burned with diffusion flames. The *surface / volume* ratio is a key parameter for the speed of combustion: \[ S / V \uparrow \Rightarrow \text{time} \downarrow \]

Although the smouldering (flameless combustion) is interesting in some applications, in most cases the solid fuel is burned with flame (due to the release of volatile matter)

Typically, fuel is fed by gravity in combustion fixed beds. When pulverized, it is fed by a pneumatic system
Fuel feeding by gravity

- Agitated container
- Screw
- Oscillating tray
- Rotating tray
- Belt
- Rotating star and screw

Pneumatic transport

- By vacuum
- By pressure

Pneumatic feeding

Pressure tank
Feeding of liquid fuels

Liquid fuels can be pre-vaporized or liquid phase fed to the combustion zone.

Although there are some applications with combustion from liquid films, in almost all cases the liquid is atomized (both to pre-vaporization and to combustion).

The atomization strongly increases the $S/V$ ratio of the liquid.

The atomization may be mechanical or pneumatic.

- Mechanical atomization: simpler and more economical.
- Pneumatic atomization: more efficient and with better control.
Classification of the atomizers

- Energy source
  - Pressure energy
    - Pressure atomizer
      - Atomizer with rotation chamber
    - Simple atomizer
  - Kinetic energy
  - Centrifugal energy
  - Sonic energy
- Type of atomizer
  - Pressure atomizer
  - Two fluids atomizer
  - Spinning atomizer
  - Sonic atomizer
  - Film atomizer with gas assistance
  - Flat jet atomizer with gas assistance
Mechanical atomizers

Pressure atomizers

- Continuous injection
  - Opening / closing controlled by the pressure

- Intermittent injection
  - Opening / closing controlled by an outside source

Primary liquid
Secondary liquid
In Diesel and Spark Ignition engines ignition is intermittent

In traditional Diesel engines the beginning and end of injection is controlled by the (intermittent) pressure of the fuel. The pressure increase forces the needle to move, hence opening the injector and allowing injection to occur.

In engines with *common rail* the fuel is always pressurized. The movement of the needle is controlled by a solenoid (more recent engines have piezoelectric injectors, which have faster response than solenoids).
In Spark Ignition engines the fuel must be completely vaporized when the (intermittent) ignition takes place

The fuel may be *sucked* to the air flow (carburettor)

Or it may be *pushed* (injection). It can be injected into the intake manifold, into the nozzle of each cylinder, or into the combustion chamber

*Injection of gasoline*

*Injection of gas – the liquid is previously vaporized*
Mechanical atomizers (continuation)

- Spinning atomizers
  - spinning disc
    - Liquid feeding tube
    - Sharp corner
    - Spinning disc
    - Rotation axis
  - spinning cup
    - Film of liquid
    - Air
    - Spinning cup
Pneumatic atomizers

**Internal mixture**

- Air - liquid

**External mixture**

- Air - liquid

**Pneumatic assisted film**

**Air – liquid atomizers**

**Vapour – liquid atomizers**

- Liquid
- Air
- Mixing chamber
- Jets of air
- Liquid
- Air
- Air
- Large droplets
- Small droplets
- Water vapour
- Liquid
- Water vapour
Sprays and droplets characteristics

Sprays are characterized by its opening angle and its shape.

They are also characterized by the diameters of droplets and their distribution.

Sprays typically contain a wide range of droplets diameters between 1 and 300/400 µm.

There are various average diameters. The Sauter (representative ratio \( \text{volume} / \text{surface area} \)) being very used:

\[
SMD = D_{32} = \frac{\sum N_i D_i^3}{\sum N_i D_i^2}
\]

\(N_i\) is the number of droplets in the interval \(i\) and \(D_i\) is the mean diameter in that interval.
Pre-treatment and heating of fuel-oil

The fuel-oil must be filtered, cleaned, decanted, separated from the water, etc., before being sent to the power system. Once there, it has to be filtered again.

Filtering is especially important in the case of engines, due to very small holes of the injectors, particularly in diesel engines (µm for the smaller diesel engines).

Due to its high viscosity, the fuel-oil must be heated to be pumped and then heated even more to be properly atomized:

<table>
<thead>
<tr>
<th>Fuel-oil</th>
<th>$T_{pumping}$</th>
<th>$T_{atomization}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light</td>
<td>10 ºC</td>
<td>65 ºC</td>
</tr>
<tr>
<td>Medium</td>
<td>25 ºC</td>
<td>95 ºC</td>
</tr>
<tr>
<td>Heavy</td>
<td>40 ºC</td>
<td>120 ºC</td>
</tr>
</tbody>
</table>
**Disintegration of liquid in a spray**

The way the liquid disintegrates in a spray is essential to obtain the desired droplet size and distribution.

The instability of liquid jet or film coming out of injector and in contact with gases leads to disruption of the jet or film, resulting in a balance of cohesive forces (surface tension) and forces between liquid and gas (resistance).

Fluctuations in the liquid can be spread in certain conditions and promoting disintegration into droplets.

The process is characterized by the Weber number (ratio between the forces exerted on the droplet surface and the cohesive forces):

\[ \text{We} = \frac{\rho_{\text{air}} u_{\text{rel}}^2}{\sigma_{\text{liq}} r} \]

\[ We_{\text{crit}} \approx 12 \]
Feeding of gaseous fuels

The supply of gaseous fuels is easier and easier to control. However, great caution is needed for safety reasons, particularly if premixed combustion is used.

The control is done by varying the gas pressure and/or the size of the output nozzle.
Feeding of the oxidizer

Usually, the oxidizer is air, oxygen enriched air, or pure oxygen.

The air can be sucked, blown or pressurized. The pure oxygen is usually pressurized.

The air supplied with the fuel is called primary air, and the air supplied to the combustion zone is called secondary air.

Sometimes there is tertiary air. Typically it is designed to involve, protect, cool, ..., the combustion zone.
The shape and velocity of the oxidizer flow largely determine the shape of the flame and its stability.

The supply of air for combustion in fixed grid beds (whether the air is blown, whether it is by normal buoyancy circulation) largely determines the thermal power released in combustion.

In many situations, especially with solid fuels and the fuel-oils, the air is preheated.
Burners

In large part, the burners are the ending part of the feeding systems already analyzed.

The burners have several functions relevant to the system:

- mixing
- ensuring complete combustion
- ensuring a fast ignition
- ensuring the presence of the flame in the entire area of interest but avoid contact of the flame with cold walls
- ensuring silent operation
- ensuring stable flames (with no flashback nor blowout/blowoff)
- ensuring uniform energy distribution
- preventing the extinction of flame in operation
- being easy to build and maintain
- having a suitable service life
Coal mills
Combustion chambers (and zones)

Combustion occurs in a specified zone, which may or may not be limited by walls. In the first case the shape of the combustion chamber has an important role in the aerodynamics of combustion (together with the burner and the oxidizer supply). In the second case it is dependent only on the aerodynamics of the burner and supply of oxidizer (and auxiliary gases, if that is the case).

In some cases the combustion chamber is intended only to provide hot gas. In other cases, the chamber has its own specific functions (heat exchange, work, ...)

- Heat transfer by convection
- Heat transfer by radiation
- Volatile matter and fixed carbon
- Combustion air
- Coal + air for coal transport
- Water / vapour
- Water
- Combustion products and flying ashes
Fluidization regimes

In fluidization solids are suspended and behave together as a liquid. Increasing the speed of the gas bubbles are formed and the entrainment of particles increases. These are recirculated on the outside.

- **Fixed bed or incipient fluidization**
- **Fluidized bed**
- **Circulating bed**
- **Pneumatic transport**
Fluidized bed

The bed consists of a mass of sand, ash, refractory and other inert materials (or not), where coarsely crushed coal is introduced. Preheated air is introduced from below along the bed, and combustion takes place within the bed. The control is done by controlling the temperature and the bed compartmentalizing.

The concept of fluidization can be interpreted in different ways:

“simple”  circulating  pressurized
The operating temperature is relatively low (800 to 1000 ºC)

The control is done by controlling the temperature and compartmentalizing

The fluidized bed combustion has many advantages:
– high rates of heat transfer between the bed and the heat exchangers
– retention of high amounts of sulphur (with iron and limestone) and other pollutants in the bed (depending on the composition of the latter)
– low emission of NO\textsubscript{x} due to low operational temperature
– ...
## Some features of burning solid fuels

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Process of combustion</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pulverized</td>
</tr>
<tr>
<td>Efficiency of combustion (%)</td>
<td>99</td>
</tr>
<tr>
<td>Global thermal efficiency (%)</td>
<td>35-45</td>
</tr>
<tr>
<td>Excess of air (%)</td>
<td>15-50</td>
</tr>
<tr>
<td>Particle size of the fuel (mm)</td>
<td>&lt; 0,5</td>
</tr>
<tr>
<td>Temperature of operation (°C)</td>
<td>1400-1700</td>
</tr>
<tr>
<td>Emissions of NO(_x)</td>
<td>High</td>
</tr>
<tr>
<td>Capture of SO(_x) (%)</td>
<td>–</td>
</tr>
<tr>
<td>Turndown *</td>
<td>5:1</td>
</tr>
<tr>
<td>Maximum electric power (MW)</td>
<td>1000</td>
</tr>
</tbody>
</table>

* Ratio between the nominal capacity (power) and the minimum operating capacity
Combustion chambers -
types, geometries, various configurations

In the combustion chambers of the furnaces, where the aim is to exchange heat by radiation, the arrangement of the set of burners may take various configurations.
Very large furnace

Furnaces with water at the bottom for wet capturing of the ashes

Cyclone furnace burners

Dry bottom furnaces

Furnace with reversed burners to obtain higher fuel burn time
Industrial boilers (medium size)

1. Long curved pipes without difficult corners make the boiler easy to clean
2. Combustion chamber can easily take 10" long firewood
3. Combustion chamber is 21.6 inches deep
Burning of coal

- fixed grid

- pulverized

Heat transfer by convection

Heat transfer by radiation

Water / vapour

Solid fuel

Matéria volátil

Air

Fixed carbon

Combustion products

Combustion products and flying ashes

Volatile matter and fixed carbon

Air for combustion

Coal + air for coal transport

Combustion

products

Water

Ashes
Burning in solid fixed grills

Feeding from above or from below

Vibrating grill

Movable grill
Combustion chambers for gas turbines

Can combustion chamber

Annular combustion chamber
Schematic view of major installations furnaces