SUBMERGED COMBUSTION HEATING AND EVAPORATION

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INTRODUCTION

Submerged Combustion is a method of direct contact heating that has been practised in a wide range of industries for several decades. This article explains the basic concepts of submerged combustion and how it can be applied to process heating of industrial aqueous solutions and slurries, and to the evaporation of solutions for the purposes of concentration or volume reduction.

WHAT IS SUBMERGED COMBUSTION?

The concept of submerged combustion is quite simple. Submerged combustion is the process of burning a fuel in a combustion chamber that is submerged in a liquid or slurry, which enables direct contact of the combustion gases with the liquid. Heat transfer from the gas to the liquid is completed rapidly and efficiently. The gases rise to the surface of the liquid and leave at, or near, the same temperature as the liquid. Submerged combustion is capable of achieving in excess of 99% thermal efficiency.

WHERE CAN SUBMERGED COMBUSTION BE APPLIED?

Submerged combustion can be used to heat or evaporate aqueous based solutions and slurries. It is often used to heat aggressive liquids or slurries that are challenging to heat by indirect methods. There are no heat exchange surfaces to foul which makes submerged combustion well suited to the heating of scaling liquids. Deposits from solutions are also problematic in conventional evaporators.

Submerged combustion has been successfully applied to heat

- Potash brine
- Sulphuric acid heap leach solution
- Log chest water containing suspended wood fibre and dissolved lignin
- Process water containing high levels of chloride
- Sea water for LNG vapourization
- Waste water from industrial plants to maintain aerobic activity during winter
- Municipal sludge for pasteurization and production of Class A biosolids
- Fresh water for process use
- Iron ore concentrate slurry at 65% solids
- Brine for iodine recovery

Submerge Combustion has been used to evaporate

- Produced water from oil and gas wells
- Brine from hide curing
- Reverse osmosis rejects
- Salt whey
- Calcium chloride solution
- Metal acid leach solution
- Landfill leachate

WHAT DO YOU NEED?

Submerged combustion systems comprise these fundamental elements:

- Container
- Fuel source
- Combustion air
- Burner
- Submerged combustion chamber
- Exhaust gas outlet
- Burner control and safety
- Process control

Container

Submerged combustion systems can be mounted in a tank or any liquid containment that is deep enough to accommodate the submerged chamber. They are commonly installed in cylindrical or rectangular tanks, constructed of metal, fibre reinforced plastic, or concrete (above or below grade). Systems have also been installed on floating barges to heat ponds, and in earth or concrete channels to heat flow streams.

The design of tanks needs special attention paid to the dynamic nature of submerged combustion. The impact forces imparted to tank walls by liquid turbulence inside the tank are substantial and are transmitted to the support structure. These forces can induce structural vibration and this must be taken into account in the design.

The container must also be able to withstand corrosive and/or erosive effects of the liquid or slurry. Materials of construction for metal tanks range from bare carbon steel to exotic alloys. FRP and dual laminate tanks have also been used commercially, as has concrete, both bare and lined.

Fuel Source

The most common fuel for submerged combustion is natural gas, although other gaseous fuels such as propane or butane can also be used provided the burner is properly configured to handle these fuels. #2 fuel oil can also be used but requires atomization, typically with high pressure air, to render it combustible in the burner. Heavy and high sulphur fuel oils such as Bunker C are not suitable.

The calorific value of the fuel can be a determining factor in the maximum capacity of a particular burner, so it may influence the quantity of burners needed to meet the heat demand of the process.

Combustion Air

A source of air is needed to support the combustion process and it must be delivered to the burner at a pressure sufficient to overcome all of the resistance in the system. In the case of submerged combustion, the greatest resistance is the hydrostatic head of the liquid/slurry that must be overcome by the combustion gases exiting the chamber into the fluid.

Combustion air is typically supplied by a centrifugal or positive displacement blower. The energy required by the blower is heavily dependent on the combustion chamber submergence which is dictated by the burner characteristics and the liquid/slurry properties, most notably the specific gravity. Other factors such as the design of the gas outlet from the combustion chamber will also contribute to the blower power requirements.

The blower must be selected carefully to ensure that it can meet the range of conditions that will be demanded by process conditions. Blowers have minimum flow limits due to surging or overheating, and these can limit the amount of turndown that can be achieved on the burner. This problem can be overcome to some extent by using excess air blowoff to prevent blower damage and still meet the process requirement.

The Burner

Not all burners are suitable for submerged combustion applications. The burner must have low sensitivity to backpressure. A short flame length is advantageous in reducing the combustion chamber length, and hence the submergence depth.

Tighter environmental standards is a driver promoting the use of low emission burners. An advantage in submerged combustion is that these burners tend to have shorter flame lengths for equivalent heat release.

Turndown capability is another factor that can influence the selection of a burner.

The burner flame temperature from is typically in the 1500° to 1650°C range.

Submerged Combustion Chamber

Submerged combustion chambers are typically cylindrical in shape, with openings at the bottom to allow the hot combustion gases to escape and sparge into the liquid. They are commonly fabricated from steel or alloy plate. The surrounding liquid acts as an effective heat sink and cooling medium for the wall of the chamber. Because there must be space above the liquid for the inert gases (N_2, excess O_2, CO_2, and water vapour) to escape and be vented out of the heating container, the section of combustion chamber above the water line is not submerged and must be cooled to prevent heat damage.

Cooling of the non-submerged portion can be accomplished by dousing it with externally sourced cooling fluid, such as the fluid being heated, or it can be lined with a refractory material to shield the metal shell from the high gas temperatures. Some proprietary designs promote self-cooling and therefore need neither external cooling nor refractory lining.

Refractory linings can be highly problematic in submerged combustion chambers. The presence of water vapour inside the combustion chamber after a shutdown, due to backfilling of the chamber when the combustion air pressure is removed, can cause condensation onto and into pores of the refractory on cooldown. Upon restart of the burner, the rapid increase in temperature can volatilize the moisture and cause spalling of the refractory, leading to premature failure.

Exhaust Outlet

The products of combustion will invariably include trace levels of carbon monoxide and oxides of nitrogen, both of which can be toxic. Therefor it is imperative that the exhaust gases be vented in a controlled manner and not allowed to escape or accumulate in the workspace. For this reason, the heating container must have controlled release of the exhaust through an engineered vent, and the rest of the container must be sealed gas tight to prevent fugitive emissions.

The sparging of gas into a liquid creates high levels of turbulence at the liquid-gas interface. Fine droplets of liquid can be formed and transported with the gas, and these droplets will report as suspended particulate in the stack gas. This may or may not be an environmental concern depending on the nature of the entrained particulate, their concentration and/or quantity, and the site specific environmental permits.

Burner Control and Safety

Burner control deals primarily with flame safety, ensuring that the burner and its ancillary systems are functioning safely. The safety requirements are dictated by standards established by organizations such as CSA, NFPA, FM and CEN. The safety functions are typically monitored by microprocessors or dedicated PLC's. They are designed to ensure that safe operating conditions exist before and during burner operation.

The heart of the flame safety monitoring is the flame detector. For continuous unsupervised operation of a burner for more than 24 hours, a self-checking flame scanner is prescribed by the standards.

The control of fuel and combustion air flow must be performed in tandem to ensure that sufficient combustion air is available in the burner and combustion chamber to support complete combustion of the fuel. This control can be accomplished by mechanically by directly linking the fuel flow device with the combustion air control valve. This necessitates characterization of the devices relative to one another. However, variable environmental conditions, such as ambient temperature, can alter the relationship, thereby upsetting the ratio of air to fuel. Inadvertent changes in the settings can also occur, for example by accidentally impacting the mechanical linkage.

Direct flow measurement of fuel and air flows can be a more reliable means of controlling the air and fuel flows. This usually requires some sort of electronic controller and actuators for the fuel and air. The use of volumetric metering devices is commonly used for flow measurement. These, however, can be subject to changing conditions such as a change in air density. The use of mass flow measuring devices, such as thermal dispersion meters, has the ability to compensate for changing conditions.

Process Control

A submerged combustion system must include process controls. The firing rate of the burner must be controlled to achieve the desired process temperature or evaporation rate. The liquid in the container must be maintained at a minimum level at all times to avoid overheating of the combustion chamber.

Monitoring the level in a submerged combustion tank can be challenging because of the turbulence in the liquid bath and at the liquid surface. There is significant gas holdup in the bulk liquid which can occupy up to 20% of the apparent bulk volume of the liquid. Devices such as external stilling wells coupled with radar or ultrasonic level transmitters have proven successful in many situations.

PLC's are commonly used to control the process parameters, but the peculiarities of submerged combustion must be taken into consideration when selecting instrumentation and control schemes.

HOW DOES IT WORK?

The process begins with starting the combustion air blower. The blower must overcome the hydrostatic head of liquid that resides in the combustion chamber at startup, forcing the liquid out of the chamber. Once the chamber is purged, a spark igniter is energised and fuel introduced into the burner to initiate a flame. Once a flame is established and the flame stabilized, the process can be ramped up to operating conditions.

The hot combustion gases exit the combustion chamber and contact the liquid, transferring their sensible heat energy to the liquid. Some of the water of combustion is condensed, thereby transferring the latent heat to the liquid. The gases leave in a fully saturated state, carrying with it not only the sensible heat, but the latent heat of the vapourization of the water vapour.

The gas leaving the liquid is at the same temperature as the liquid which is in contrast to a boiler-heat exchanger combination in which exhaust from the boiler is at much higher temperatures.

The saturated gas from submerged combustion contains an amount of latent heat related to the humidity ratio as shown on psychrometric charts. It can be seen in Table 1 and Figure 1 that the enthalpy in the saturated gas increases rapidly with temperature. This is the primary efficiency constraint associated with submerged combustion. Therefore, a higher liquid temperature leads to less thermal efficiency. Some of this latent heat can be recovered by contacting the incoming cold feed with the exhaust gas. This action condenses water vapour and the latent heat is absorbed into the liquid thereby preheating it before it enters the submerged combustion container. This is being practised with some proprietary design. Because of this phenomenon of latent heat carried by the exhaust gas, it is impossible to boil water by submerged combustion. The reason is that at a certain temperature, which occurs below the boiling point, the amount of energy contained in the water vapour in the saturated gas is equal to the amount of energy that is input into the liquid by the burner. At sea level, pure water can only be heated to about 85°C. Dissolved solids will increase this temperature due to vapour pressure depression effects of the solute.

It is this phenomenon that can make submerged combustion an effective evaporator. The evaporated water that is carried out with the exhaust gas offers opportunities for the recovery of high quality water by condensing the vapour directly into a suitable process stream, or indirectly with a condenser and cooling medium.

Table 1. Humidity Ratio and Enthalpy of Saturated Air

PSYCHROMETRIC DATA		
Temperature °C	**Humidity Ratio kg water / kg Air**	**Enthalpy of Saturated Air kJ / kg dry air**
0	0.0038	27
5	0.0054	37
10	0.0077	47
15	0.011	60
20	0.015	75
25	0.020	94
30	0.027	118
35	0.037	147
40	0.049	185
45	0.065	232
50	0.087	293
55	0.115	372
60	0.154	478
65	0.206	621
70	0.279	720
75	0.386	1110
80	0.553	1557
85	0.838	2321
90	1.420	3876

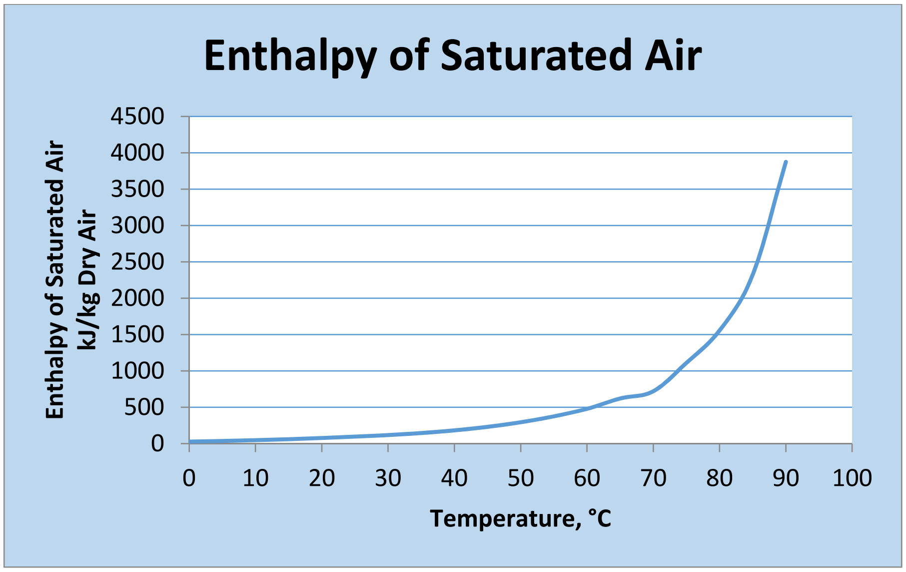

Figure 2. Enthalpy of Saturated Air

SUMMARY

Submerged combustion is a heating technology that offers an effective method of heating difficult solutions and slurries with high thermal efficiency. Higher efficiency compared to conventional indirect heating results in lower energy consumption and lower greenhouse gas emissions.

The absence of heat transfer surfaces makes submerged combustion a good candidate for fluid with scaling characteristics.

The evaporation of waste water streams is a growing field of application for submerged combustion. It reduces haulage of waste water to disposal sites, eliminates discharge of liquid to waterways, and can recover high quality water for re-use which lessens the draw on fresh water resources.

Submerged combustion has proven to be an effective, efficient and reliable technology for process heating and evaporation.