Under pressure, underground

Gravity pressure vessels could efficiently turn waste into biofuels, argues **Peter Hurrell**

MANY chemical processes work better using sub-critical or superheated water under pressure. These conditions have been used in the chemical and food industry for over 180 years, for example in dilute-acid hydrolysis of celluloses and starch to saccharides, in the extraction of instant coffee, when extracting indigo dye from woad and for treating wastewater sludge through wet-air oxidation.

In all of these applications, the process used has generally remained a batch procedure where the water is pumped into a pressure tank and a heat exchanger. After treatment the resulting liquid is returned through the heat exchanger, which pre-heats the inflow, then a pressure-regulating valve before being released to normal pressure. The process depends on energy-intensive mechanical and electrical pumps and pressure tanks. It has mostly been used for small-scale production since the mixing requirements and the need to add chemicals while maintaining temperature and pressure limit the potential for scale-up.

James Titmas in 1967 modified the process with the aim of making the best use of the pressure and heat from the sub-critical water process. His goal was to convert biomass to useful materials using wet oxidation, pyrolysis and hydrolysis.

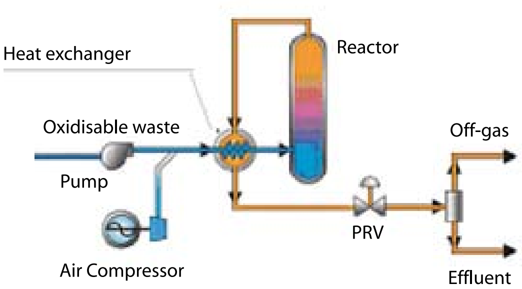
To this end, he placed the pressure vessel below ground in a borehole or well. Using gravity and heat from the process as a heat pump minimises the amount of energy needed to drive the pump and creates continuous flow. Another advantage is that being underground makes for efficient thermal insulation, a small plant footprint, and improved health and safety. To obtain the natural pressure needed to maintain the temperature in subcritical water, the reactor has to be placed no more than 2200 m underground. This is within the capabilities and expertise of the oil industry. The accuracy and skill of drilling wells vertically, straight and lining them to preserve water aquifers is also well proven.

The technique has been proven in use: The US Environmental Protection Agency (EPA), together with Bow Valley Energy, used an 1300 m deep vertical tube reactor (VTR) based on a 1982 patent by J McGrew for the wet-air oxidation of sewage sludge with heat recovery at Longmont, Colorado. After modification, parts of this plant, as patented by D Sillerud, were moved to Apeldoorn, Netherlands, where it was used to treat sewage sludge from 1992 to 2004. The plant out-performed all its design expectations. In the later years the use of Taylor bubble and heat recovery was abandoned in favour of product recovery following the Titmas approach.

The gravity pressure vessel (GPV) provides a simple way of making the sub-critical water process continuous: it uses the heat released from the controlled wet oxidation of process contaminants to drive the water flow, much in the same way as an autogenic thermal airlift pump. This greatly increases production capacity because the GPV works as a continuous, linear, plug flow reactor with very high internal heat and pressure recovery and no moving parts. This makes the process easy to control and scale up without the need for multiple arrays of pumps, pressure tanks or complex controls.

The GPV comprises a long steel pipe, shaped like a test tube, of a fixed diameter between 300–600 mm. An open-ended steel pipe creates updraft and is suspended within the test tube. This updraft protrudes above the test tube and descends to within a few metres of its concave bottom. Small bore steel pipes are suspended in the updraft to inject steam, chemicals, for temperature control, cathodic protection and cleaning, etc. The diameter of the test tube and updraft pipes are governed by hydraulics of the supercritical water and the need for a self-cleansing velocity as well as the small bore pipes.

The whole GPV is freely suspended inside a steel-lined borehole, which is cemented into the ground. A pressure cap is placed over the space between the GPV and the borehole and a vacuum is applied to the void between the enclosed space to form a thermal barrier between it and the borehole. Through the top of the GPV the pipes connecting to the GPV includes a feed solution to the annulus formed between the updraft and the test tube; and a pipe for discharging the treated solution from the updraft with the smaller pipes at the top. The process defines the



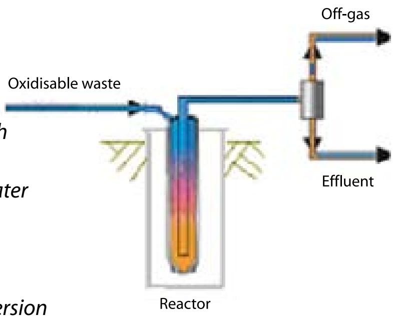


Figure 1: A batch process using superheated water under pressure
Figure 2: The continuous underground version

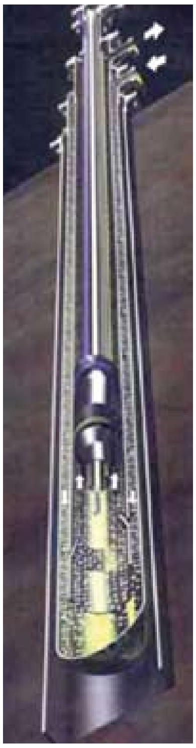
Figure 3: Apeldoorn sludge treatment plant (below) Figure 4: Gravity pressure reactor

depth of the GPV.

GPV for wet-air oxidation of sludge

Wet-air oxidisation of sludge should be carried out at a depth of 1500 m. Sludge at 3–6% dry solids passes down the outer annulus and oxygen is injected near the bottom. Oxidation is rapid, raising the temperature to 2400°C. The treated waste rises through the updraft to the outlet for final treatment, degassing and heat capture. As it rises, it passes heat through the updraft to pre-heat the descending sludge prior to oxidation. The process achieves 95+% destruction of BOD/COD (biological/chemical oxygen demand) and neutralises all inorganic material.

Since sludge can be processed as a liquid, it can be taken directly from sewage treatment works; there is no need for expensive drying as required for other processes such as incineration. The process is self-sufficient in energy and even generates a surplus, which can be converted into electricity.



GPV for dilute-acid hydrolysis of biomass

Dilute-acid hydrolysis of cellulose to sugars requires a 610 m deep GPV. The biomass mash containing 8–12% dry solids flows down the outer annulus and steam is injected at the bottom to initiate a temperature rise. Oxygen is added at the entry to the updraft to burn off dissolved lignin, followed by acid. As the cellulose disassociates to saccharides, the temperature rises to 2380°C. An alkali is injected, immediately neutralising the acid. Once autogenic thermal balance is established the steam supply is cut. Heat from the rising saccharide solution passes through the updraft to pre-heat the cellulose mixture, descending in the outer annulus. Using the GPV increases the efficiency of converting biomass to sugars two- to three-fold, greatly enhancing the potential of producing ethanol for biofuels and other applications.

Most ethanol today is made from crops rich in sugar and starch, most of which are food crops. With increasing demand for fuel, more of these have been grown, but despite this there are concerns that this is making food more expensive, fuels inflation and could lead to food shortages. The competing uses of land for food and fuel have gone from a non-topic to headline material, and urgently needs a solution. Using GPV in sub-critical water to convert non-food biomass to ethanol could be an important part of the solution.

Ethanol can be made profitably from a wide range of biomass sources including non-food crops. Other potential raw materials include waste from farming, agriculture, forest clearings, parks and gardens; food, drinks manufacture and expired product; industry and commerce; sawmills and paper manufacture; paper, cardboard and packaging; cotton and linen; municipal solid waste (MSW) and sewage sludge. Using these wastes as raw materials, we could supply the large quantities of ethanol required to meet biofuel targets, without hurting global food production.

Using MSW as a raw material has the added advantage of being a steady source of biomass throughout the year which is unaffected by seasons, climate, disease or international pricing cartels. Whilst the yield of ethanol from such a raw material may be lower compared to the yield from other sources, this can be offset with treatment fees.

The process can assist the household waste industry because it changes a waste material that currently incurs a cost to treat to a raw material that can creates an income from treatment. As biomass represents around 66% of MSW in the EU (87% and more in Asia) it is profitable to convert to ethanol. Sewage sludge, which contains around 30% biomass, can also be treated and converted in the plant.

MSW-to-ethanol facilities work in three identifiable stages. The first is preparing the biomass by shredding, settlement in water to remove inert materials, maceration, and thickening. The second is to treat the biomass with supercritical water, and passing it through a further settlement tank and molecular sieves to clean it. In a third stage, the contained saccharides are converted to ethanol. The process plant and equipment used are standard to the water industry, and are enclosed and covered. There are no airborne emissions from the treatment of waste. Dioxins cannot be produced since the working temperature is low. Smells and particulates are avoided. Water from the process is recycled and any residual will be treated for discharge to inland waterways. The carbon dioxide produced can be used as the acid in the hydrolysis reaction, with the rest available for sale or sequestration.

Using MSW to make ethanol betters all existing and projected environmental targets for treatment. It eliminates landfilling and cuts out the greenhouse gases that would otherwise be emitted from landfill or from the treatment process. The process is entirely carbon negative and qualifies for carbon credits. Ethanol made from MSW offers major benefits towards biofuels substitution targets in any country without affecting the food economy.

An MSW to ethanol plant is affordable. Its capital cost can be significantly less than 40% of an equivalent incineration plant, and is simple and more economical to operate and maintain. The income from the sale of ethanol can finance the design, construction, operation and maintenance of a plant within a few years without fees increasing above current landfill charges.

There are other areas where waste can profitably be converted to ethanol. One example is paper. In 2006, the UK and Ireland alone collected some 4m t of paper and shipped it to China. Whilst this recovered paper may not be suitable in manufacturing new paper, it is worth converting to ethanol fuel. In fact, the practice was used in the UK until the 1970s, when it was abandoned in favour of cheap North Sea oil.

summary

Supercritical water is an environmentally benign solvent that has many applications. Until recently it has been used in a batch process, but GPV makes it possible to turn this process continuous.

GPVs also find their use in the wet-air oxidation of sewage sludge, which produces surplus energy, but the quantity of sludge that can be treated in a stand-alone treatment facility is limited to the larger urban conurbations or regional centres.

A particularly interesting application of GPV is in the conversion of biomass to saccharides in order to make ethanol fuels, using dilute-acid hydrolysis. This process can be economical using a wide range of biomass materials, including non-food crops and waste such as MSW. Whilst the yield of ethanol from some materials may be higher than MSW, this can be offset with a treatment fee. The process also promises an environmentally-friendly solution for municipal waste and an alternative to landfill and incineration. The company Genesyst, which has developed and patented a GPV reactor with the aim of transforming MSW to ethanol, calculates that a comparable MSW-to-ethanol plant can cost less than 40% of an equivalent thermal destruction plant.

The process is not dependent on food crops such as wheat and maize, but takes commercial advantage of industrial waste with a high cellulose content such as paper and wood, MSW (after separation of the recyclable materials), sewage sludge and other cellulose materials that would otherwise be disposed of.

The ethanol produced is an effective use of bio-energy resources, in terms of both greenhouse gas emissions and value-for-money, which takes on board the wider environmental impacts, and contributes to sustainable emission reductions needed to fulfil a low carbon economy.

Figure 5: An artist's impression of a proposed MSW-to-ethanol plant

The gravity pressure vessel cited here was invented and patented by James Titmas, the founder, chairman and ceo of Genesyst International. **tce**

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