Taking a closer look at bioethanol plant design in the framework of EU policies and sustainability claims

Energy saving conversion processes

In 2007 the European Commission put forward an integrated energy/climate change proposal that addressed the issues of energy supply, climate change and industrial development in the EU.

To achieve the renewable energy policy goals set out, a directive was proposed in early 2008. This aims to establish an overall binding target of a 20% share of renewable energy sources in energy consumption in 2020 and a binding 10% minimum target for biofuels in transport to be achieved by each member state.

Compared to fossil sources biofuels cost more than other forms of renewable energy and without a separate minimum target for biofuels, they will not be developed. According to the European Commission[1] this matters because greenhouse gas (GHG) trends are worst in transport, and biofuels are one of the few measures – alongside vehicle fuel efficiency – realistically capable of making a significant impact on GHG emissions from transport.

In addition, the oil dependence of the transport sector is the most serious security of supply problem. Finally, there must be investor certainty in the biofuels industry regarding the objectives and the pathway to be followed.

With a capacity of 1.25 million litres per day the distillery of Jilin Fuel Ethanol is Asia's largest bioethanol plant and at the same time the largest multi-pressure distillation system realised by Vogelbusch

What the EU wants

In terms of sustainability the policy is that biofuels must achieve a level of at least 35% GHG savings and respect a number of requirements related to biodiversity. For instance no raw material from undisturbed forests, bio-diverse grassland or nature protection areas must be processed and all EU biofuels must meet agricultural cross compliance rules. If biofuels do not meet these criteria they do not account towards the EU target and are not eligible for tax exemption or similar financial support at both the EU and national level.

By setting stringent environmental sustainability standards for biofuels the Commission expects to encourage the development of better types of renewable energy. Next generation biofuels, produced from wastes, residues, non-food cellulosic material, and ligno-cellulosic material, have the advantage of more significant GHG savings and therefore the Commission's proposal foresees that such biofuels will count double against the 2020 production target.

R&D scenarios for next generation biofuels concentrate on managing competition for land resources, increasing the yield per hectare and developing energy efficient and reliable biomass-to-fuel conversion processes. Next generation biofuels are at the very early stages of the development process and great efforts are still necessary to make the large-scale commercialisation possible. Therefore, first generation biofuels will continue to dominate the market in the near term.[2]

Sustainability and efficiency of first generation plants

While concerns have been raised about whether first generation biofuels are sustainable, production technology has come a long way since the beginning of biofuels programmes in the 1980s. Driven by cost savings, energy-conscious design has since reduced the energy demand of the process by up to half.

Energy efficiency is a proven, cost-effective way of cutting GHG emissions and contributing to sustainability. Tightly connected to sustainability is the efficiency of plant operation, the reliability of the process, a high level of plant availability, and process yield. Two crucial points in energy design are the fermentation system and the thermal integration of the process units.

Improving fermentation efficiency

An economically successful and efficient alcohol fermentation process at the same time allows for:

High yield – achieved through minimum formation of by-products such as lactic acid and glycerol and a low amount of residual sugars and dextrin left in the fermented mash before it enters distillation.

High stability and reliability – especially from the biotechnological point of view to minimise plant shutdowns.

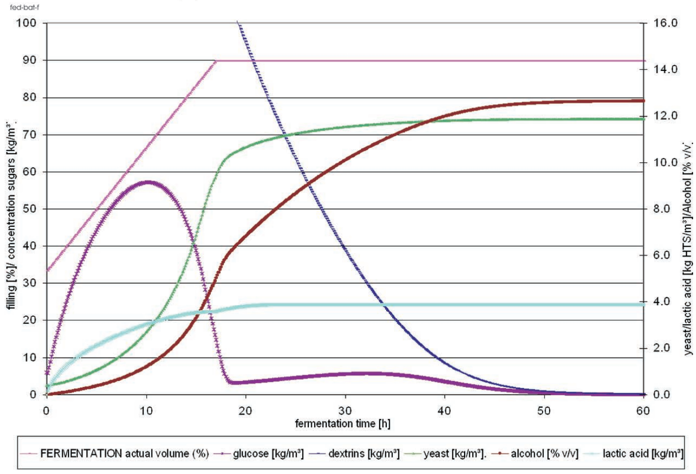
Simple process – minimises expenses in labour and/or automation.

High productivity – reduces the required fermentation volume.

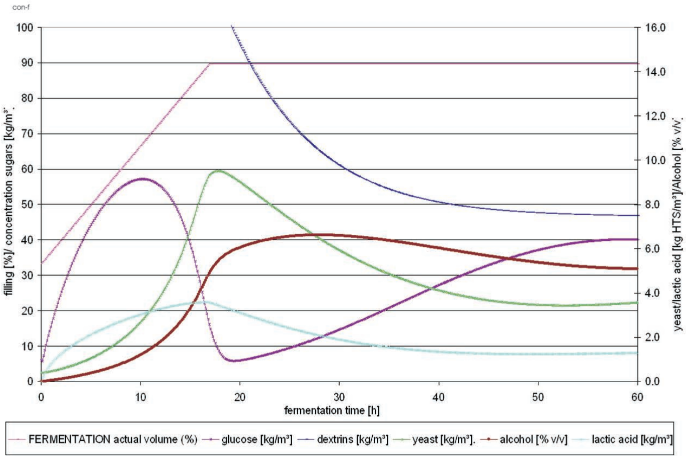
The impact on plant efficiency can be illustrated by comparing the most common fermentation methods, fed batch and continuous operation. The process curves are calculated using a kinetic model of the alcohol process, which mainly considers inhibitory and limiting effects of substrate, alcohol and by-products on yeast growth and alcohol formation. Model parameters were verified with process data from laboratory trials as well as from large-scale operations. (Basis: fresh yeast 0.4 kg/m^3, substrate wheat).

The first process graph shows the course of fed batch fermentation. When inoculated, the fermentation tank is partially filled with substrate. Further substrate is added afterwards in a controlled way to keep the parameter of fermentation at the optimum. Compared to batch fermentation, cell density is increased by less initial dilution, thus the degree of infection is decreased compared to a batch system. However, during the start there is still a period without alcohol protection in mash.

During fed batch mode, inhibition of substrate can be controlled. At the beginning the media in the tank is very dilute, which is also true for the concentration of inhibitors entering the fermentation by substrate. This situation enhances yeast growth during the first phase of fermentation. Alcohol concentration reaches 4 % v/v after about 15 hours. By-product formation is lower than in a batch process, but still significant.



Fed batch fermentation



Continuous fermentation

Continuous fermentation

The second process curve shows the course of continuous alcohol fermentation in the first tank of a cascade of normally five to seven fermenters. Continuous fermentation is first started similar to fed batch fermentation. Once tank filling is completed, the substrate flow stays constant and the alcoholic mash leaves the system at the same rate. In this phase of operation, cell density is high and there is a reasonable concentration of alcohol in mash.

Continuous alcohol fermentation is a so-called chemostat. The most important parameter – the dilution rate – can easily be controlled. As long as an organism's growth rate is higher than the dilution rate of the tank it stays and grows in the system. All organisms that grow slower than the dilution rate of the tank are washed out. Therefore the parameters of mash are kept in a range that only the growth rate of the yeast is higher than the dilution rate. Consequently only the yeast will stay in the system, whereas all other germs entering the fermentation with the substrate or directly from the environment are washed out.

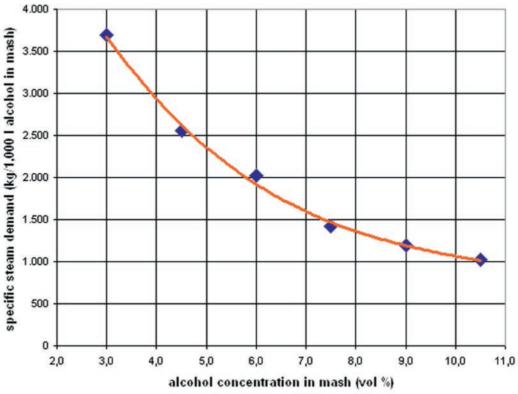
Infection: no trouble whatsoever

It has been observed that even if the degree of infection is high during start up the number of contaminants drops as soon as the system operates in continuous mode.

In the subject case it was assumed to continue with fed batch operation for about 20 hours. At that time alcohol and yeast concentration but also formation of inhibiting by-products have reached a significant level. When switching to continuous operation the by-product formation significantly decreases to levels lower than in any other fermentation techniques.

In a well-designed continuous fermentation plant, infection is no higher than one bacterium per 100 up to 1000 yeast cells once steady state has been reached. This low degree of infection makes very high yield possible combined with high alcohol concentration in the mash. At the same time the potential to recycle stillage, vapour condensate and singlings is maximised.

Especially in grain-based plants this gives continuous operation a number of advantages compared to other techniques, one of them being higher volumetric productivity: the biomass content in continuous processes is permanently high. In batch systems the frequent filling and emptying of tanks lowers the fermentation volume and the biomass concentration fluctuates, but on average is much lower. Continuous grain fermentation manages with 40% less fermentation volume compared to optimised batch processes.



Impact of alcohol contraction on the steam demand implemented with the superiour Vogelbusch Multipressure distillation system with split columns

It is obvious that from the handling point of view batch processes are much more complicated. Operation has to be intermittent, which either leads to increased interventions by operator or to a high degree of automation. The automation of a continuous system is significantly less expensive.

The parameters yield, alcohol concentration in final mash and recycling rates of stillage, singlings and vapour condensate are parameters that are directly linked. Continuous fermentation performs better in respect to these parameters because of permanent high cell mass in the system and a lower degree of by-product formation.

An advanced continuous fermentation process can achieve high alcohol concentration in the mash. A properly designed grain fermentation system reaches up to 13%, or perhaps even 15% with starch milk as raw material.

Other advantages making continuous fermentation to the method of choice for efficient production are significantly lower cleaning requirements (on average every 4 to 6 months; whereas in batch processes CIP has to be carried out after each cycle) and the safety of operation.

Minimising energy demand by thermal integration

System of thermal integration	Traditional	Medium integrated	Fully integrated
Raw material preparation	700	300	300
Distillation/rectification/dehydration	3500	2000	1250
Evaporation	1800	0	0
Drying	2650	2400	2400
Total plant steam demand	**8650**	**4700**	**3950**

Thermal integration reduces the energy consumption (figures in kg life steam per 1000 l alcohol in fermented mash)

Energy demand and GHG emissions

Some 10-16 % of the costs of production of bioethanol are caused by the consumption of thermal energy. Therefore reduction of the use of energy is one of the key requirements in the design and construction of bioethanol plants.

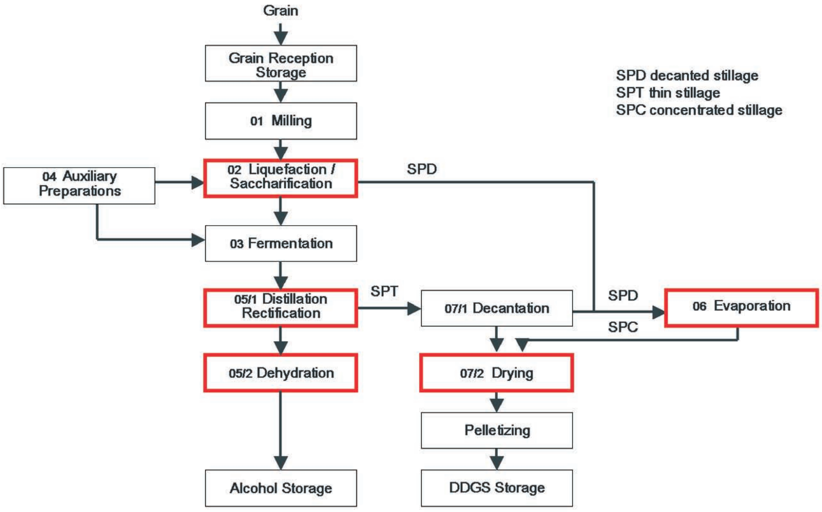
The red boxes in the block diagram show the dominant thermal processes in grain-based bioethanol production. Considered as single process steps in a low-integrated wheat processing facility, the total consumption of thermal energy would split up as follows:

- 10% are consumed in liquefaction/saccharification
- 30% in distillation/ rectification/dehydration
- 20% in a three-stage evaporation plant
- 40% in DDGS drying

By recovery and reuse of secondary energy from process compounds and thermal integration in the units of single process steps and the plant as a whole the most considerable reduction of primary energy demand is possible.

Stillage plays an important role in the recovery and reuse of secondary energy from process compounds as it can lower the energy demand in two ways. Firstly, the higher the dry substance content in the stillage, the lower volume and water to be evaporated – this leads to reduced capacity and steam demand for stillage evaporation. Secondly, the heat of the recycled stillage is utilised in the liquefaction process. In addition to reducing the overall water demand of the plant, stillage recycling can provide approximately one-third of the liquefaction energy requirement.

The highly structured impacts of such systems require careful design to ensure process stability and fermentation performance.



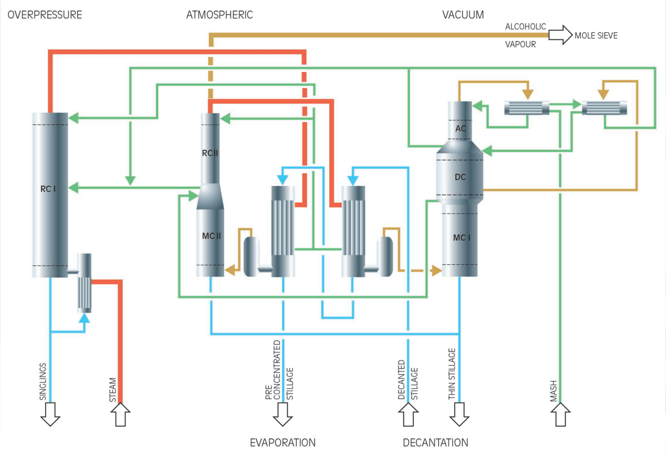
Production of bioethanol from grain - the red boxes refer to dominant thermal processes

The most advanced thermal integration system

One of the most advanced energy saving systems used to date in the production of bioethanol is the Vogelbusch Multipressure distillation system with split columns in combination with thermal integration of rectification and dehydration. The basic principles are shown on the flow sheet.

The distillation/rectification unit consists of three columns operated at different pressure levels. The mash column and the rectification columns are split to balance the energy streams. Steam is used only to heat the first rectification column. The first mash column is heated with the heads of the second rectifier. The heads of the rectifier are used for heating the second mash column. In addition, both heads are used at the same time for stillage preconcentration, reducing evaporation load by approximately 45%.

Besides rectification is integrated with the dehydration process. The dehydration is carried out by molecular sieve technology. Thermal integration is realised through the feed of alcoholic vapours from 2nd rectifier to the molecular sieve units. In this way, the latent heat of the feed vapours of the rectified alcohol is used with the result that practically no steam demand exists for dehydration. The latent heat of the alcoholic vapours remaining after dehydration is normally also recovered. In the present case it is used for mash preheating.



Vogelbusch Multipressure distillation with split columns

The effect of energy savings on GHG emissions:

		Specific consumption per m³ bioethanol	GHG emission kg CO2e/m³ bioethanol
Provision of raw material			
corn (63% starch)	kg	2475	960
Conversion			
natural gas	MJ	17800	1103
electricity	kWh	300	150
By-product credits			
DDGS	kg	869	- 231
electricity export	kWh	930	- 464
Total GHG savings vs. petroleum	**%**	**- 44**	**1518**
(petroleum = 128,47 kg CO2e/MJ)			

Estimation of GHG emissions at a highly integrated Vogelbusch plant in central Europe (corn feedstock, natural gas steam boiler, DDGS production)

Ultimately the stillage may contain inhibiting substances that affect fermentation. It also increases the viscosity of the mash, which may have a negative impact on the performance of the evaporation plant. The resulting limitations of the recycling rate depend on the raw material and have to be observed accordingly.

A traditional grain-based bioethanol plant built during the 80s in the US had a low level of both integration between process steps and stillage recycling, distillation/rectification as a single pressure system and dehydration of bioethanol by entrainer distillation.

The steam demand of a medium-integrated system first built in the US during the 90s is characterised by a higher degree of stillage recycling to raw material preparation, thermal integration of distillation/rectification with stillage evaporation and molecular sieve dehydration (pressure-swing adsorption).

The steam demand of a fully integrated bioethanol facility as seen in modern facilities shows a significant difference in that distillation/rectification is designed as multi-pressure system with split columns and stillage evaporation is exclusively heated with off-gasses from DDGS drying.

By thermal integration and process optimisation the steam demand of a wheat-processing bioethanol facility has been reduced from approximately 8.5 tonnes per thousand litres down to below 4 tonnes today.

When using an energy-saving conversion process GHG savings are already well below the sustainability criteria for biofuels as outlined in the EC Directive Proposal which sets the minimum threshold at 35%.

Still further savings will be achieved in future for first generation plants. On the one hand by further optimisation of the conversion process, alternative by-product concepts and the application of alternative, biomass-based energy supply concepts, and on the other hand by a significant reduction of the emissions related to the raw material supply by using optimised grain varieties and improved plantation methods.

Conclusion

Biofuels is the first sector that needs to produce under very stringent conditions under the EC Directive. The biofuels industry[3] welcomes and supports the proposed sustainability criteria. The GHG emission saving targets are ambitious but they are technically possible as shown above and thus biofuels will deliver a substantial carbon dioxide saving. Moreover, biofuels used in the EU will be the most sustainable in the world.

The minimum 10% target for biofuels in the EU by 2020 is one of the key elements in this Directive. The obligation will bring certainty to the young EU biofuels industry to further invest in this sector and promote research and development.

Still there are elements in the proposal the biofuels industry puts up for discussion. The Directive will deliver a substantial contribution in reducing our dependency on full fuel for road transport. Therefore the fossil fuel comparator drawn in the proposal needs to come down to earth (the 83.8 gCO2eq/ MJ reflect only the very light crude from the Middle East where in reality biofuels will also replace environmentally damaging heavy crude from Canadian tar sands or from deep sea drilling.)

There also needs to be a level playing field between the use of agricultural crops for food and non-food and also between biofuels and fossil fuels with sustainability criteria for all of them – the Directive can set a trend towards more sustainable production in all sectors. ●

For more information

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[1] European Commission: Memo on the Renewable Energy and Climate Change Package, http://ec.europa.eu/energy/climate_actions/index_en.htm

[2] F.O.Licht's World Ethanol and Biofuels Report, Vol 6, No 12, Feb 26, 2008

[3] eBIO, press release 2008 01 23, www.ebio.org