Geothermal steam for glycol plant

Gunnlaugur Friðbjarnarson, Teitur Gunnarsson, Gunnar Herbertsson
VGK Consulting Engineers Ltd, Laugavegur 178, 105 Reykjavik, Iceland
Email: gunnlaugurf@vgk.is, teitur@vgk.is, gunnar@vgk.is

Abstract

Chemical processing includes in wide terms the application of chemical reactions, mass and heat transfer. Traditional obstacle to utilisation of geothermal steam for chemical processes has been the limited steam temperatures and pressures available from the geothermal fluid separators. In a prefeasibility study of a plant for manufacturing of various glycols from sugars the viability in using geothermal steam for all main heating and separation tasks has been estimated. A model calculation based on chemical functional group contribution methods shows better separation behaviour at lower pressure and temperatures. This enables the use of medium pressure steam (10-15 bar) for 95% of all thermal tasks. Only a minor part of the process tasks requires higher temperature where the heating media has to be 250–300°C. This temperature can be obtained from a conventional high-pressure boiler system. Process optimisation and systematic re-utilisation of heat has reduced the steam consumption and enhanced the overall economy. Approximately 50 MW_{th} of geothermal steam is needed to produce 120.000 tpa glycols and alcohols and the low steam pressure required gives more options in locating the glycol plant. Fundamental problem in locating such a plant remains to find a steam source close to a harbour for ocean going vessels to minimize inland transport cost.

Keywords: *geothermal steam, chemical process, glycols, sugar, molecular contribution, UNIFAC modelling.*

1 Introduction and project background

International Polyol Chemicals Inc. (IPCI) of Oregon, USA, has developed a proposal for a chemical process for making certain polyols or glycols that are widely used in the food-, plastics-, pharmaceutical- and cosmetic industries. In the IPCI process sugars produced from corn, sugar cane or sugar beets can be used as raw material (Chao et al., 1982a, 1982b; Sirkar, 1982, 1983; Huibers et al., 1984).

Archer Daniel Midland (ADM) in Decatur, Illinois, USA constructed a 5.000 tpa pilot plant for continuous conversion of sorbitol into glycols according to the IPCI process in 1989-1990. A feasibility study for Industrial Development Corporation of South Africa (IDC) of a 100.000 tpa glycol plant located in the Republic of South-Africa was completed in 1996 (Fluor Daniel, 1996). The idea was to use a new refining process to convert low value sugars from molasses into clean invert sugar syrup to be used as feedstock for the glycol plant. Sugar cane molasses is a low price product that can be purchased widely and processed into high percentage invert sugar syrup. Figure 1 explains the basic operational principles in a plant producing polyols from sugars or molasses with hydrolysis of sucrose. The IDC feasibility study showed a potential for the application of IPCI technology assuming certain conversion, product slate and yield that still had to be confirmed in a pilot plant.

A feasibility study for the Iceland Ministry of Trade and Industry and Icelandic investors of a similar plant in Iceland was finished in 1998. One of the factors that made the Icelandic project feasible was the low-cost geothermal steam available (IPCI and BYGGD-VGK, 1998).

2 Pilot plant operation

IDC realised the importance of generating reliable data prior to designing an industrial plant and took actions in order to answer some basic questions. To demonstrate the sugar to glycols process and generate basic data for the process design a pilot plant was built in USA and erected at Transvaal Suiker Beperk (TSB) sugar mill in Komatipoort in the Mpumalanga province in the Republic of South Africa in 1999 (Brix and Orth, 2001). The plant consists of eight modules or skids on which the production and purification of the products occur. In addition to the eight modules there are several auxiliary modules: hydrogen production, nitrogen production, vacuum header and an oil heater.

During initial operation many problems occurred. Heat exchangers, pipes and pumps became blocked by sticky material, hydrogen production and compression failed frequently, metal leached from the catalyst in the reactors, insects plugged fluid filters. Equipment failures and lack of funds for remedial actions led to a stop in the project in mid 1999.

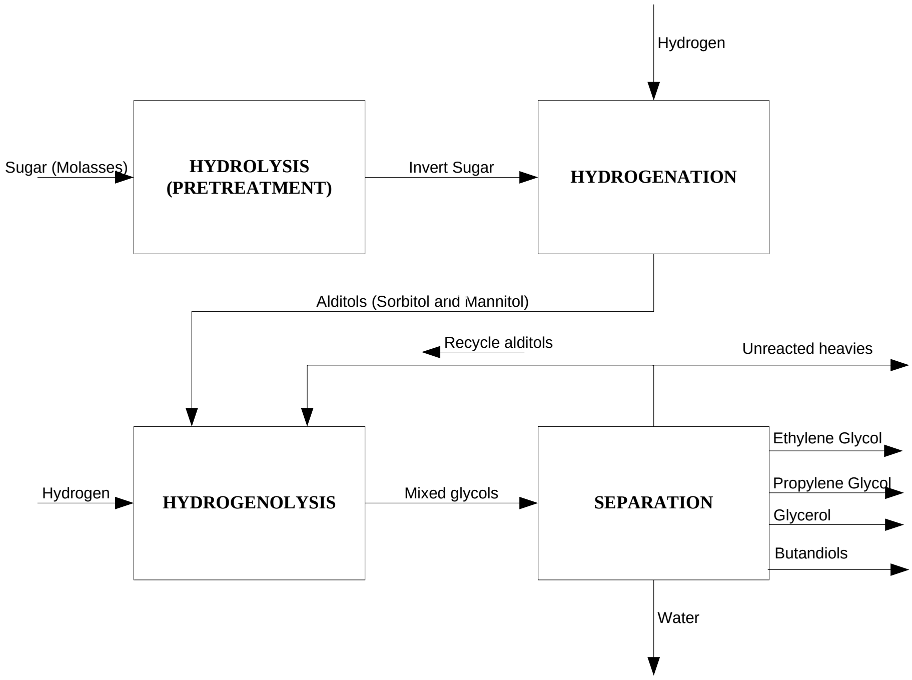

Figure 1: Simplified process flow sheet of the "Sugar to Polyols" process.

3 Icelandic partnership

IceChem, an IPCI subsidiary, was established in Iceland in 1996 to promote a sugar to glycols plant located in Iceland, based on the IPCI technology and utilising the low-cost geothermal steam. After facing the serious setback in the pilot plant operation in 1999, IceChem founded Icelandic Green Polyol Inc. (IGP) with the participation of several Icelandic investors. IGP decided early 2001 to invest in the refurbishment and operation of the pilot plant.

An agreement between IPCI, IDC, TSB and IGP for joint funding of refurbishment and operation of the pilot plant was reached in April 2001 and signed in September.

The refurbishment work on the pilot plant started in April 2001 and included major reconditioning and redesigning of some of the production steps, renewing some

equipment and instruments. The pilot plant control system was extensively upgraded and reprogrammed.
The start-up, which was scheduled for September 2001, was delayed by various equipment failures as well as hydrogen delivery problems. Continuous glucose hydrogenation was started at the end of October 2001. From January 2002 the operation has basically performed continuously. The pilot plant is automatically controlled by a computerized control system and is operated 24 hours a day, 7 days a week.

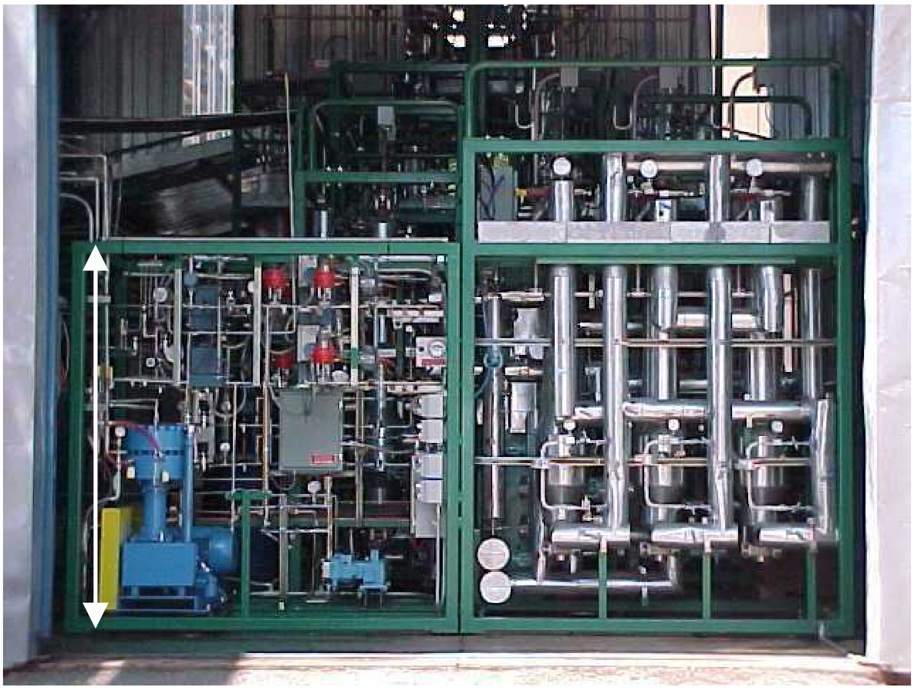

Figure 2: Front view of skid 1 & 2 of the pilot plant, feed & hydrogenation section (arrow length app. 2,2 m).

4 Information from pilot plant operation

Extensive tests have been done in the pilot plant on all fundamental production steps, including hydrogenation, hydrogenolysis and separation of glycol products.

A lifetime test of a catalyst in a 2.000 h operation resulted with a moderate decline in the catalyst activity. Washing and regeneration of the catalyst restored its activity.

All operating steps simulating a real process performed and over 2.000 kg of glycol products have been made during the first year of operation.

Extensive tests of water removal, fractional distillation of product mixtures and distillations for glycol purifications were also made.

Fundamental studies on chemical and physical behaviour of the product mixtures and its individual components have been made and new information generated.

A better understanding of the process has been achieved and the operating team is pioneering continuous running of sugar to glycols trickle bed process.

5 Geothermal steam for glycol plant

The process can generally be described as water based hydrogenation and hydrogenolysis of sugars in a trickle bed reactor, followed by water removal, glycol evaporation and glycol separation. This includes in wide terms the preparation of raw material solutions, handling of the reaction mixtures during reactor operations and thermodynamical tasks.

In feasibility study made for IGP (IPCI Engineering, 2003) new and revised capital cost estimate is done as well as renewed and redesigned concepts for the industrial operation for a 120.000 tpa polyol plant located in Iceland. One of the main tasks in the plant will be an economical removal of approximately 1.700 tpd of water from the process streams. This water will be reused and recycled within the process.

Table 1 shows the temperature levels of individual production steps within a polyol plant.

Table 1: Operational tasks and corresponding temperature and pressure.

Operational Task	Temperature °C	Possible Equipment	Possible heat source	Steam pressure bar a
Alcohol distillation	50-70	Distillation column	Under-pressure steam	0,3-0,6
Hydrolysis of sugar	60-90	Tanks	Recycled hot water	n.a.
Water evaporation	60-120	Multi-effect evaporator	Low-pressure steam	2-5
Hydrogenation	100-150	High-pressure reactors	Low-pressure steam	2-5
Glycol evaporation	100-150	Multi-effect evaporator	Medium-pressure steam	2-8
Glycol separation	110-150	Distillation columns	Medium-pressure steam	10-15
Hydrogenolysis	200-280	High-pressure reactors	High-pressure steam	40-50

Conventional petrochemical processes use heat sources mainly in the temperature range from 200-1000°C. This high temperature eliminates the possible use of geothermal steam in such processes. In the sugar to glycol process the main heating tasks consume steam with pressure lower than 15 bar. It is therefore clear that a geothermal steam source can be very beneficial for a full-scale industrial operation.

6 Process optimisation

Former work on the separation of glycols by distillation mainly uses steam source with pressure of about 20 bar and temperature of 212°C. The only logistically interesting geothermal field in Iceland that has been explored and can deliver such pressure is the Reykjanes field. Other Icelandic geothermal fields relatively close to harbour are either not explored or cannot deliver this high pressure.

Investigating glycol thermodynamics by the use of molecular contribution methods like UNIFAC or UNIQUAC modelling (Fredenslund et al., 1975; VDI-Wärmeatlas, 1994; Randhol and Engelien, 2000), indicates better separation effect by lower system pressure and therefore lower temperature. This enables the use of medium pressure steam of 10-15 bar as thermal driving force for the polyol plant. Only approximately 5% of the thermal energy required needs to be supplied at higher temperature. This can be done using conventional boiler, using plant purge gas or by-product alcohols as fuel.

The temperature gradient within the plant gives interesting possibilities for the systematic re-utilization of latent heat of product and condensate streams. The result of the IGP feasibility study (IPCI Engineering, 2003) indicates a total steam consumption of approx. 700.000 tpa or approximately 50 MWth. This is approximately third of the steam consumption estimated by previous work (Fluor Daniel, 1996; BYGGD-VGK, 1998). The economical benefits are obvious.

To describe one of the main problems regarding product separation and purification, an example of the separation of a binary system Diol-A (1) and propylene glycol is used as a reference. Very little data is available in the literature. Therefore a model based on the UNIFAC concept with the pure compounds vapour pressure data as a reference was used to make vapour-liquid equilibrium calculations for the system at different pressures.

Those calculations strongly indicate process benefits by lower system pressure and therefore lower temperatures. This knowledge is one of the main keys for using steam of medium-pressure, 12 bar, instead of 20 bar steam as initially assumed. This might lead to several new options for locating such plant. A capital cost estimate also shows that it is becoming more interesting to build a transport pipe for the steam from the geothermal field to a harbour site. This would eliminate inland trucking of raw materials and products; avoid duplicate product storages and higher operating costs due to operation on two sites.

Results of the model calculations are shown in Figure 3 and Figure 4 in T-x-y diagrams. When the system pressure is 50 mbar the gap between the boiling curve and the dew point curve is significantly larger than at 500 mbar. However because of this narrow gap relatively little enrichment is gained in each operating step. Technically this means high distillation columns filled with structural packing with large internal surface area with low pressure-drop characteristics. The corresponding McCabe-Thiele diagram is showed in Figure 5. Test runs in the pilot plant have confirmed the above discussed calculations and predictions.

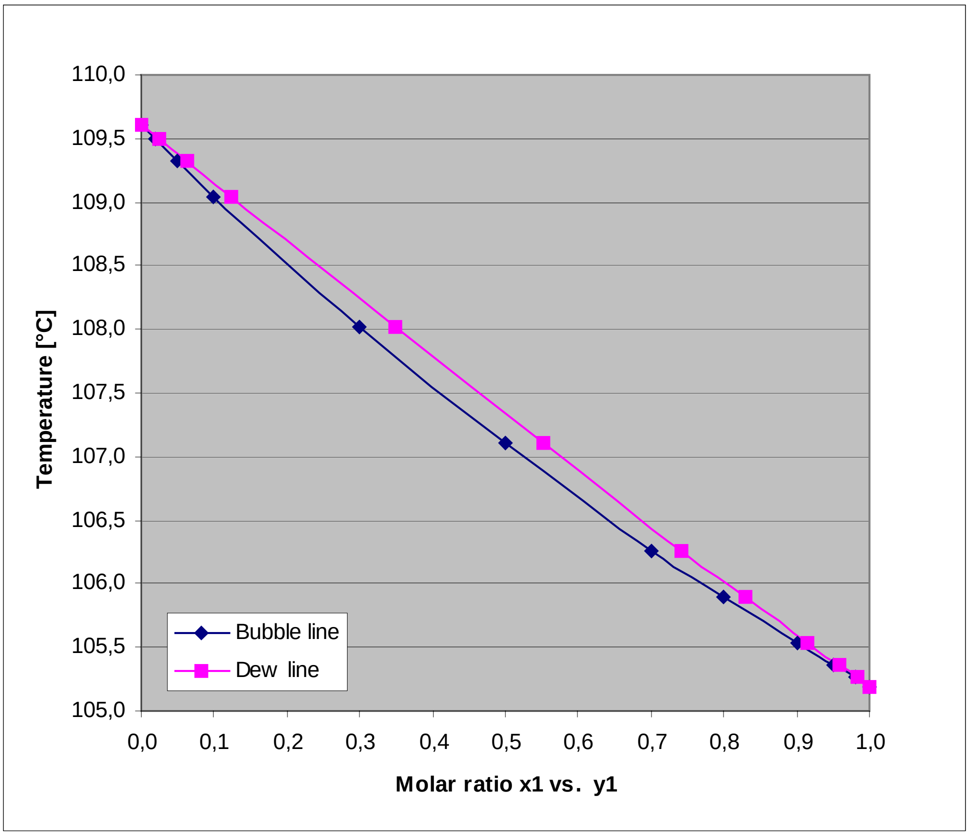

Figure 3: T-x-y Diagram for Diol-A (1) and 1,2-Propylene glycol at 50 mbar system pressure.

7 Conclusions

Model calculations based on the UNIFAC molecular contribution method led the way in developing more efficient distillation system for a glycol plant using steam of lower pressure than earlier anticipated. This lower pressure is more suitable for the Icelandic geothermal fields and more options in locating the glycol plant might now be available.

Process optimization and systematic re-utilization of latent heat has lowered the calculated steam consumption considerably and enhanced the process economy. Approximately 50 MWth of geothermal steam is needed for the production of 120.000 tpa of glycols. Small amount of high-pressure steam for the plant can be produced using purge gas and by-product alcohols as fuel.

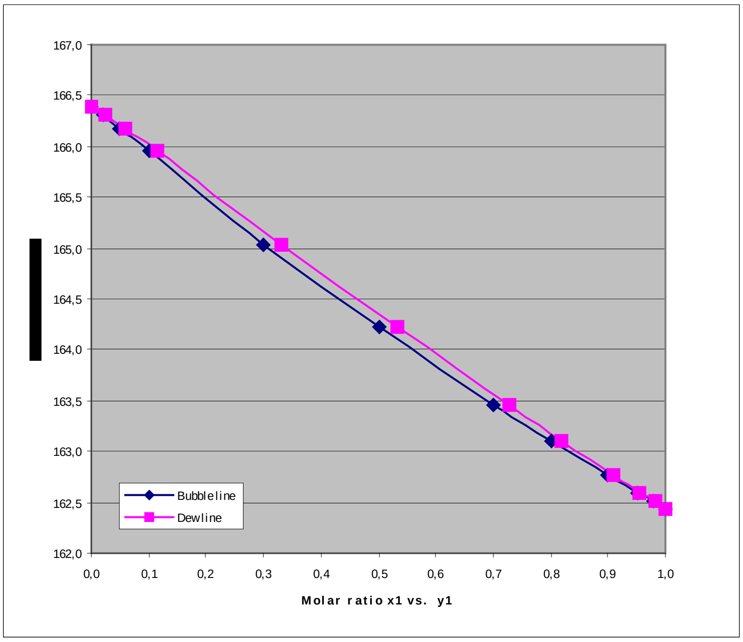

Figure 4: T-x-y Diagram for Diol-A (1) and 1,2-Propylene glycol at 500 mbar system pressure.

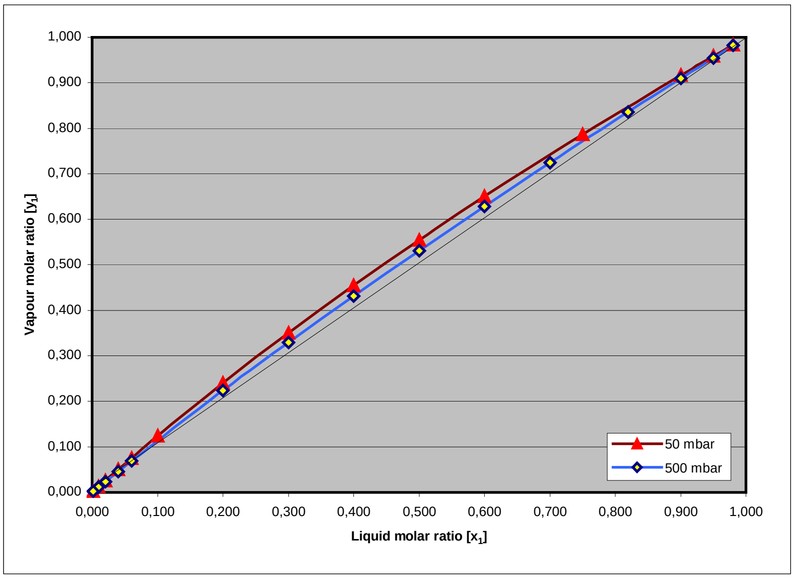

Figure 5: McCabe-Thiele diagram for Diol-A [1] and 1,2-Propylene glycol with Unifac models.

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