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CO_2 recovery systems for craft brewers

Dalum Beverage Equipment Aps
Søndersø, Denmark

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TECHNOLOGICAL INNOVATION | Five years ago, CO_2 recovery in small breweries was both economically unviable and technically impossible, but Dalum Beverage Equipment Aps, Søndersø, Denmark eliminated both obstacles and have been installing their CO_2 recovery units to craft breweries left, right and centre. This article covers in detail the technological innovation the company has successfully implemented in a very short time.

DALUM BEVERAGE EQUIPMENT was founded in December 2019 by Kim Christian Dalum, based on his almost 30 years of experience in developing and managing global engineering businesses within beer pasteurization, packaging, all-round cold block and CO_2 recovery. The aim has always been to design and manufacture advanced technology to allow small brewers, vintners, and distillers to purchase and utilize technology previously only available to large producers. Due to the small scale of craft brewing in terms of capital equipment buying power, advanced technologies for improving efficiencies of raw materials, energy, water, and minimizing waste streams and environmental impact, which are used by large brewers/producers, have not been marketed towards nor affordable for craft sized operations. As a result, while the consumers' experience as regards beer selection and flavours is widely considered superior with craft beer compared to standard lagers, on a per hectolitre basis, craft brewers' production costs exceed those of a large brewer, and their environmental impact in terms of water usage, liquid waste and CO_2 losses is also relatively higher.

Dalum units in operation

While trying to develop a solution to help craft brewers reduce beer losses through beer recovery from surplus yeast at Ørbæk Brewery four years ago, Kim Dalum was challenged by Master Brewer and today Production Manager Andreas Falkenberg to shift focus to CO_2 recovery, as he did not see craft brewers being keen on mixing beer from the yeast-waste-stream into proudly crafted beer. As CO_2 recovery was already a potential project in the drawers of Dalum Beverage Equipment, they decided to shift focus and listen to the customers. It has in the meantime been a long journey as no components or systems used as standard for manufactures of large CO_2 plants have been available on this scale, and for sure not at affordable prices. Moreover, the physics and thermodynamics could not just be scaled down 1:1.

In December 2019, Dalum installed the first CO_2 recovery unit at Ørbæk Brewery, and it has been in production for three years, undergoing several improvements and tests along the way. Ørbæk uses CO_2 for both soft drinks and beer, and still needs supply from an industrial gas company. The second unit has been in operation in Svaneke Bryghus for two years, and the brewery has been self-sufficient with their own natural CO_2 ever since. Svaneke is even able to sell surplus CO_2 in cylinders, along with kegged beer, to bars etc.

In total, almost a dozen Dalum CO_2 units have been installed and another two dozen are in the pipeline.

Feed gas collection manifold

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Purification and liquefaction

The purification and liquefaction process of the Dalum CO_2 unit is based on traditional, tried-and-tested processes but it uses different process parameters and components. The CO_2 feed coming from the fermenter is (when the oxygen level is below about 1%) connected to the CO_2 collection stations featuring pressure regulators controlling individual fermenter pressures and simultaneously allowing recovery of purge gas from empty fermenters or bright beer tanks.

From here, the CO_2 feed gas is led to the water scrubber via a foam trap. After the scrubber, the CO_2 is pressurized in the patent-pending stainless steel 3-stage compressor to the condensation pressure. It then passes through two adsorption stages, one for dehydration and removal of remaining traces of volatiles and one for possible H_2S removal. Condensation takes place in the patent-pending condenser system using an external or integrated chiller, followed by the transfer to a vacuum insulated CO_2 storage tank or CO_2 cylinders.

Several combinations of adsorbers and absorbers with different desiccants have already been and will continue be tested. For now, Dalum have settled with water scrubbing as the most important process for removal of impurities, followed by regenerable dehydrators for removal of moisture and remaining traces of volatiles, sulphur components and nitrogen-based molecules. Removal of traces of DMS has been the main challenge in terms of purification, as DMS can be detected as an off-flavour in beer by the human sense of smell at concentrations as low as 0.1 ppm, and traditional regenerable aluminium oxide or activated carbon adsorbents do not seem to be able to adsorb DMS to zero in this application. By combining advanced regenerable aluminium oxide adsorbents, Dalum has reached a stage where no traces of DMS are detected by a trained taste panel in clean CO_2 or after a bubble test in cold water. This might not be super important when recovered CO_2 is used in beer, but it is important for customers using recovered CO_2 in soft drinks or sparkling water. This has been made possible by now using a molecular sieve with high adsorption capacity of sulphur components in the dehydrators, in combination with an advanced aluminium oxide adsorber providing optimum adsorption of water, alcohols, aldehydes, ketones, ethers, peroxides, mercaptans, sulphides and nitrogen-based molecules as ammonia, amines, and nitriles. Table 1 below lists the typical concentrations of other components we have found in CO_2 from craft breweries, followed by the concentrations after our different purification steps. For measuring raw CO_2 concentrations, burette and gas detection tubes were used. For the purified CO_2, the method of choice was a combination of gas chromatography analysis, gas detection tubes, burette and an Orbisphere dissolved oxygen analysis performed by Ramsgate Brewery, UK. The values found can be compared to the maximum values set by ISBT, International Society of Beverage Technologists, for food grade CO_2 also listed in the table, and used by industrial gas companies as reference.

CO_2 collection, Fat Lizard, Finland

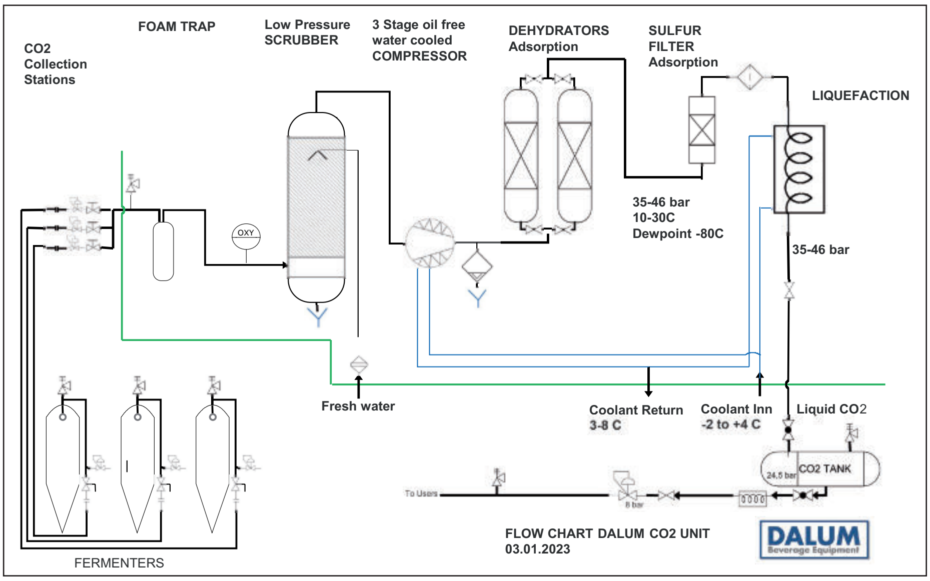
CO_2 compressor

It is worth noticing that no hydrogen sulphide in concentrations above 0.05 ppm was ever detected in the raw gas at any of the craft brewers Dalum have worked with. However, the company is still using non-generable activated carbon as a sulphur filter in their units, although this is something they might change in the future.

The dried CO_2 is further purified of incondensable gases like oxygen and nitrogen in the patent-pending CO_2 condenser. The condensation takes place counterflow in the 11-meter-long condenser column where the CO_2 molecules are constantly condensed and re-evaporated for boiling and stripping out oxygen from the liquid CO_2. In the tested samples and tanks, the resulting liquid CO_2 normally exhibits a content of oxygen below 0.1 ppm, the minimum concentration that could be measured. However, at Ramsgate Brewery, an Orbisphere DO meter measured a level of only 6 ppb.

Purity levels

For guaranteed purity, Dalum still refers to ISBT, even though they achieve much better values for almost all parameters. They still need more experience to go beyond the current purity levels as they have not been able to test performance under all conditions and capacities. It would be far too expensive to measure purity and gas composition in-line on this scale, as applied in very large urea-based CO_2 recovery plants with capacities of several tons per hour. However, they have a very reliable indirect in-line measurement of the efficiency of the purification process, as their in-line dewpoint sensor measures the function of the dehydrator. When the dehydrators remove moisture, they also remove other impurities and vice versa, which leads to constant monitoring of the CO_2 dewpoint after the dehydrators. The dewpoint is consistently below –80 °C at condensation pressure, or, in other words, below 1 pm water. For quality assurance, it is recommended to test CO_2 purity from a tank sample with burette at least once a week and test for any detectable smell or taste in a bubble test with the same frequency. Materials



CO_2 recovery process, flow chart

Process overview on Dalum HMI

in contact with CO_2 in Dalum CO_2 units are food contact approved materials, and the oil free compressor and the piping is fabricated from stainless steel.

CO_2 recovery in craft breweries

CO_2 recovery in craft breweries is a new discipline, and there is a certain learning curve to climb for Dalum as well as the breweries. All learning is a bit challenging, but once the mindset and procedures are in place, it becomes just another habit. First of all, procedures for connecting the fermenters and purge gas tanks have to be established, as well as the knowledge of how to operate and maintain the CO_2 unit. If a brewery wants to be self-sufficient regarding CO_2, more work usually has to be done and more procedures learned; sometimes with great side effects.

In the CO_2 management of a brewery, there are at least two sides of the equation: one is supply and the other is usage. Dalum has focused on the supply side, so let us talk about this first. Despite of having both active and passive foam traps removing foam, foaming can be an issue with CO_2 recovery. In case of predictable foaming we have good experience with using a lightweight plastic foam trap right under the downpipe from the fermenter in addition to a stationary foam trap at the inlet to the CO_2 unit, preventing the lion's share of the foam from entering the pipe system. The brewer is master of the process and Dalum can't judge what results in the best beer, but we can share some of our observations. Dalum provides foam traps, but the brewer is encouraged to avoid relying on this, controlling FV volumes, yeast pitch rates and fermentation. Furthermore, the slight top pressure of 0.25 bar(g) required to deliver CO_2 to the unit is generally enough to suppress excess foam generation.

To recover the maximum amount of CO_2, the sequence of fermentation becomes a point of attention as well. To utilize the CO_2 recovery technology's capacity, it might sometimes be considered in the weekly planning. When a brewery decides to become self-sufficient regarding CO_2, the CO_2 recovery process becomes as central as the reliability of the brewhouse, the boilers or the cooling system. This is a learning curve the larger mainstream breweries with traditional CO_2 recovery went through as well, and it has now been common knowledge for many years. In contrast to larger breweries, who would have more technical and operational staff available even on three shifts and in weekends, craft brewers have much less staff available. Dalum helps compensating for this by offering an on-line dashboard providing a full overview of all relevant process parameters of the CO_2 unit on-line on both smart-phone or PC.

Moreover, Dalum offers remote trouble shooting services through online access to the CO_2 units' control systems and access to process parameters via a cloud set up. The other side of the equation of CO_2 recovery is the CO_2 consumption or usage, and it is very important to find a way to balance this with the supply side. Can and bottle fillers as well as kegging lines can have very different consumption profiles and just monitoring the usage and determining the right key consumption figures for each process can bring savings and be instrumental in balancing the usage with the supply. Some breweries will realize that the consumption of CO_2 is too high to be covered by their own recovered CO_2 even if they can achieve recovery rates up to 70 % with a Dalum CO_2 unit. In this case CO_2 savings could be identified on filling lines, purging procedures or by introducing loss-free in-line carbonation, but in

CO_2 storage tank delivered by Dalum along with CO_2 container bundles used during the startup phase (Fat Lizard, Finland)

Kim Dalum and the team from Stewart Brewing, Edinburgh, Scotland

the end each brewery must determine what the right level of CO_2 usage should be. In case this level is still too high to be balanced with the CO_2 supply, options like nitrogen generation, and use of nitrogen for purging and other purposes where it might replace CO_2, can be considered as a supplement to CO_2 recovery.

When a brewery starts using a new CO_2 unit, we recommend accepting the learning curve and do it step by step. Important issues in relation to this are often the brewery's pure CO_2 tank capacity, as well as how to handle the current CO_2 supplier to the brewery. It is for sure an advantage to maintain a good relation to the CO_2 supplier to ensure a back-up solution for the CO_2 supply. The breaking point is often the usage of the rented CO_2 storage tank on the brewery's premises, as gas companies are not keen on sharing the storage tank. The normal solution is therefore the brewery buying their own CO_2 storage tank – normally a good investment as storage tanks have a long lifetime, often exceeding 40 years. Even in this case, the gas companies could be reluctant to deliver liquid CO_2 to a brewery's own tank, and then the alternative is to establish a back-up solution using CO_2 cylinder bundles, a solution many brewers have as normal CO_2 tank capacity.

Benefits

Recovering a brewery's own CO_2 first of all saves costs compared to buying industrially manufactured CO_2. The variable cost is mainly the electrical power to run the unit, and we have measured about 0.2 kWh/kg CO_2 over a period of some months. The water consumption is about one to one with using industrial CO_2., 1 liter of water/kg CO_2. As with other rotating equipment running almost 24/7, maintenance is estimated to 2–3 % pa. of the capital investment. On request, Dalum offers to help brewers using their feasibility tool to determine the estimated potential for CO_2 recovery and the projected financial benefits. Depending on size, CO_2 prices and usage, we see payback time for the investments in CO_2 recovery spanning form under one year to five years (apparently Svaneke reports a pay-back time of three years). Labour cost is on level with maintenance, and with current European electricity prices, the variable cost for 1 ton recovered CO_2 should be about EUR 50.

Additional benefits are CO_2 independence and in-house control of the CO_2 source, including the elimination of traceability reporting for the CO_2 used. Independence has been the determining factor for some customers in the light of current uncertainties in CO_2 supply. For organic craft brewers it has been important to be in control of their own CO_2 source, as it is for brewers claiming to brew beer under the German "Reinheitsgebot" (purity law). Not least, CO_2 recovery eliminates the largest or second largest source of CO_2 emission from a brewery. As an example, if a 10 000 hl/year brewery eliminates the purchase of 25 tons CO_2 per year by recovering their own CO_2, they will reduce CO_2 emissions by 50 tons/year, as it causes 1 ton in emission to manufacture and bring 1 ton liquid CO_2 to the brewery. This corresponds almost to removing 40 European average petrol cars from the roads. ■

TYPICAL CHEMICAL PROFILE OF DALUM CO_2 RECOVERY

Component	Presence in feed, ppm	After water scrubber, ppm	After compressor, ppm	After dehydrator and condenser, ppm	ISBT ppm
Acetaldehyde	20	0	0	0.02	0.2
Ethyl acetate	200	10	8	0.0	
Mercaptans	5	1	0.7	0.0	0.1
Dimethyl sulfide	35	3	2	0.05	0.1
Ethanol	2500	5	0	0.0	
Carbon disulfide CS_2	0	0	0	<0.05	0.1
Hydrogen sulphide H_2S	0	0	0	<0.01	0.1
Carbonyl sulphide COS	0	0	0	<0.05	0.1
Oxygen O_2	1000	1000	1000	0.005 -0.1	30
Moist H_2O	>10000	>10000	1000	1	20
Carbon dioxide %	96	97	99	99.985-99.995	99.900
Nitrogen	4000	4000	4000	0.1	na
Amonia	na	na	na	<1	2.5
Oil and grease	na	na	na	<1	5
Hydrocarbon	na	na	na	1.5	50
Benzene	na	na	na	<0.01	2.5
Methanol	na	na	na	0.06	10

Table 1

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