On-Site Nitrogen Gas Generation for the Brewing Industry

A White Paper by Randy Peccia and Phil Green

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A New Golden Age for Beer

Derived from four primary ingredients – water, grain, hops and yeast – beer has been one of the most popular beverages for thousands of years, and remains the most popular alcoholic beverage around the world.

In recent years the global beer industry has seen exponential growth. Europe now has over 10,000 breweries with the USA growing from 500 breweries in 1990 to now over 8000.

Today, it's nearly impossible to visit a city or town that doesn't have pubs and bars displaying dozens of different beers to quench your thirst, from the well known brands to local microbreweries. In excess of 19,000 breweries now operate around the globe and the beer industry has never been more competitive.

While customers face a world of choice, their expectations have never been higher and continue to grow. Consumers are increasingly turning to familiar brands for the reassurance of consistent quality and affordability.

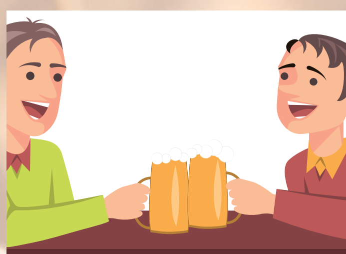
While it may seem easy enough to go to the local specialist beer shop, microbrewery, internet supplier or supermarket to buy your favourite brand, the process for brewing, bottling and taking a beer to market is quite complex. The challenge for producers is to supply consumers choice beers at the volume and cost required, while ensuring that quality, taste, colour, aroma and mouthfeel remain consistent.

European brewery statistics

> 10,000 breweries

> 134,000 direct employees

> 2.3 million jobs grain to glass



72 litres consumed per capita/year

The Beer Brewing Process

Whilst the beer brewing process can be considered both a science and an art, it can be broken down into series of defined stages, enabling those who are not master brewers to gain a simple understanding of the processes involved.

Malting
Grain is the main ingredient in the brewing process. Malting is the process of steeping, germinating and drying raw grain, such as barley, wheat, oats or rye, to convert it into malt that can be used for brewing.

Milling
Once at the brewery, the malt is passed through a mill. The mill is used to crush the malt kernels to expose their starchy endosperm. It is key to crush the malt to the size, as this impacts the taste of the final product. Too fine a grind can result in the grain forming into a flour-like powder which can create a stuck mash. Too coarse a grind and the brewer is left with an incomplete extraction of starches.

Mashing
The process of mixing the crushed malt with hot water, which typically ranges from 62-70 °C. This is a steeping process that creates an oatmeal like substance, known as the mash. The water hydrates the malt, activates the enzymes, and converts the grain starches into fermentable sugars – a future food source for the yeast. This sugary liquid, called 'the wort'(pronounced wert), becomes the body of the beer.

Lautering
Before brewing, the wort must first be separated from the spent grains as efficiently as possible. The first step of this process is called mashout, where the temperature of the mash is raised to 77°C to halt enzymatic reactions and preserve the sugar profile of the wort. Secondly, loose grain particles are filtered out by flowing the wort out of the bottom of the lauter ton and recirculating it back through the grain bed, resulting in a clearer wort. After recirculation, the wort is transferred to the boil kettle. Finally, the spent grain in the lauter ton is rinsed, or sparged, with hot water to pull as much of the remaining sugars out as possible.

Boiling
Now transferred into a kettle, the wort is brought to boil for 60-120 minutes. The main reason for boiling is to pasteurize (sterilize) the wort. Boiling also allows grain proteins to bind with tannins and precipitate out, which reduces the protein haze and flavour in the final product. During this process, brewers can add in hops or other desired flavours. Hopping the beer is what gives a beer its qualities of aroma, taste and bitterness. Lastly, a vigorous boil evaporates some of the water and concentrates the wort.

Fermenting
Following the boiling and hopping processes, the wort is transferred into a fermenter and yeast is added, but first, the wort must be cooled to a specific temperature, typically between 15-20 °C, for the yeast to do its job correctly. The function of the yeast is to consume the sugars created in the mash and turn them into alcohol and carbon dioxide (CO_2). After several days most of the wort sugars have been converted and the majority of yeast cells are dormant. However, even though primary fermentation is deemed complete, there is still yeast activity.

Conditioning
Conditioning, also referred to as secondary fermentation, takes place in either the primary fermenter tank or the beer is transferred to a secondary fermenter. This process can take a couple of weeks or even months. Its purpose is to allow the beer to mature and for flavours and aromas to mellow. This process also permits the remaining yeast to re-absorb some of the unwanted by-products of fermentation and then to settle, yielding a smoother, clearer product. It is common practice for brewers to chill the beer, known as cold conditioning, to aid the conditioning stage.

Packaging
After fermentation and maturation, the beer is filtered (but not always), carbonated and stored in bottles, cans or kegs for distribution. The quickest and most common way to carbonate the beer is force carbonation. By injecting carbon dioxide in to a container under pressure, the beer is forced to absorb the CO_2. Once packaged and carbonated, the beer is ready for enjoyment.

Note: The processes described are typical but by no means the only methods employed to produce beer.

Nitrogen in the Brewing Process

Nitrogen is a colourless, odourless and tasteless gas, which makes up 78% of earth's atmosphere. Its inert properties and natural abundance have made it a highly popular choice by brewers to use throughout their beer brewing processes.

Its main purpose is to reduce oxidation. Nitrogen is used to prevent the contact of ingredients with air. Air contains oxygen, which causes oxidation and ultimately impacts the quality and longevity of the finished product. Beer is quickly oxidized when exposed to air. If the quality of the product is to be ensured, then it needs to be constantly protected.

Blanketing of Ingredients

During storage in sealed tanks, positive pressure of nitrogen can be used to ensure there isn't air ingress when volume changes because of temperature fluctuations. If storing in atmospheric tanks, a continuous flow of nitrogen can be added to ensure that air cannot diffuse through vents and into the headspace during volume changes. Also, when moving the product from one tank to another, nitrogen can be added to fill the headspace and can be used to aid in pressure transfer within sealed systems.

Clean in Place (CIP) Pipe-Work and Vessel Purging

To eliminate any chance of contamination to their product, reducing the cost of waste, breweries often clean and sterilize storage vessels and the interconnecting piping. The products used to clean the equipment are often caustic solutions, which contain sodium hydroxide (NaOH). When carbon dioxide (CO_2) is used to push the cleaning solution through the equipment, brewers risk a chemical reaction between the CO_2 and NaOH, which forms sodium carbonate (Na_2CO_3) and sodium bicarbonate ($NaHCO_3$). This reduces the sterilizing characteristics of the solution and renders it unlikely to be suitable for re-use. The reaction between CO_2 and NaOH can also cause implosion (collapsing) of the vessel if there is no anti-vacuum fail-safe. Nitrogen does not react with NaOH, maintaining the cleaning solutions cleansing properties, allowing for reuse of the solution and eliminating vessel implosion.

Purging and Filling

Equipment and pipelines are susceptible to oxygen pick-up. Nitrogen is an effective purging gas that enables brewers to reduce water consumption. Nitrogen assisted filling increases process speed, protects the beer from oxidation, and results in substantially reduced beer losses.

Nitrogen gas, having very low solubility, forms bubbles in liquid that provide effective mixing of beer in the brewing tank. The bubbles quickly rise to the surface and are dissipated without affecting taste, appearance or aroma. This form of mixing, known as sparging, is also less production intensive than mechanical methods.

Nitrogen gas is fast replacing carbon dioxide as a method of providing motive force when discharging beer from storage tanks to filtration. Carbon dioxide can affect taste and increase product wastage due to fobbing. Nitrogen delivered at high pressure is less likely to affect carbonation.

Bottling

Purging bottles, cans and kegs with nitrogen gas helps to reduce oxidation and extends product shelf-life. Nitrogen can also be used to dry bottles after rinsing.

Nitrogenation

Using a mixture of both nitrogen (N_2) and carbon dioxide (CO_2), typically with a ratio of 70% N_2 and 30% CO_2, beers can be enjoyed with a creamy, smooth mouthfeel and a dense, persistent head of foam. This is because nitrogen is far less soluble in beer than CO_2. The smaller nitrogen bubbles cascade through the beer forming a more stable, long lasting head and a lighter, thinner feel.

Dissolved oxygen

Fresh Water Equilibrium Oxygen Surface Transfer Values (Blanketing with N2)									
Water temp °C	Dissolved Oxygen content at 100% saturation vs Generated N2 MROC @ 1013mbarA								
	20.9% O_2	5% O_2	1% O_2	0.5% O_2	0.10%	500ppm	100ppm	50ppm	10ppm
	Parts Per Million PPM/w					Parts Per Billion PPB/w			
1	14.2	3.397	0.679	0.34	0.068	33.97	6.79	3.4	0.68
2	13.8	3.301	0.66	0.33	0.066	33.01	6.6	3.3	0.66
3	13.5	3.23	0.646	0.323	0.065	32.3	6.46	3.23	0.65
4	13.1	3.134	0.627	0.313	0.063	31.34	6.27	3.13	0.63
5	12.8	3.062	0.612	0.306	0.061	30.62	6.12	3.06	0.61
6	12.5	2.99	0.598	0.299	0.06	29.9	5.98	2.99	0.6
7	12.2	2.919	0.584	0.292	0.058	29.19	5.84	2.92	0.58
8	11.9	2.847	0.569	0.285	0.057	28.47	5.69	2.85	0.57
9	11.6	2.775	0.555	0.278	0.056	27.75	5.55	2.78	0.56
10	11.3	2.703	0.541	0.27	0.054	27.03	5.41	2.7	0.54
11	11.1	2.656	0.531	0.266	0.053	26.56	5.31	2.66	0.53
12	10.9	2.608	0.522	0.261	0.052	26.08	5.22	2.61	0.52
13	10.6	2.536	0.507	0.254	0.051	25.36	5.07	2.54	0.51
14	10.4	2.488	0.498	0.249	0.05	24.88	4.98	2.49	0.5
15	10.2	2.44	0.488	0.244	0.049	24.4	4.88	2.44	0.49
16	10	2.392	0.478	0.239	0.048	23.92	4.78	2.39	0.48
17	9.8	2.344	0.469	0.234	0.047	23.44	4.69	2.34	0.47
18	9.6	2.297	0.459	0.23	0.046	22.97	4.59	2.3	0.46
19	9.4	2.249	0.45	0.225	0.045	22.49	4.5	2.25	0.45
20	9.2	2.201	0.44	0.22	0.044	22.01	4.4	2.2	0.44
21	9	2.153	0.431	0.215	0.043	21.53	4.31	2.15	0.43
22	8.9	2.129	0.426	0.213	0.043	21.29	4.26	2.13	0.43
23	8.7	2.081	0.416	0.208	0.042	20.81	4.16	2.08	0.42
24	8.6	2.057	0.411	0.206	0.041	20.57	4.11	2.06	0.41
25	8.4	2.01	0.402	0.201	0.04	20.1	4.02	2.01	0.4
26	8.2	1.962	0.392	0.196	0.039	19.62	3.92	1.96	0.39
27	8.1	1.938	0.388	0.194	0.039	19.38	3.88	1.94	0.39
28	7.9	1.89	0.378	0.189	0.038	18.9	3.78	1.89	0.38
29	7.8	1.866	0.373	0.187	0.037	18.66	3.73	1.87	0.37
30	7.7	1.842	0.368	0.184	0.037	18.42	3.68	1.84	0.37

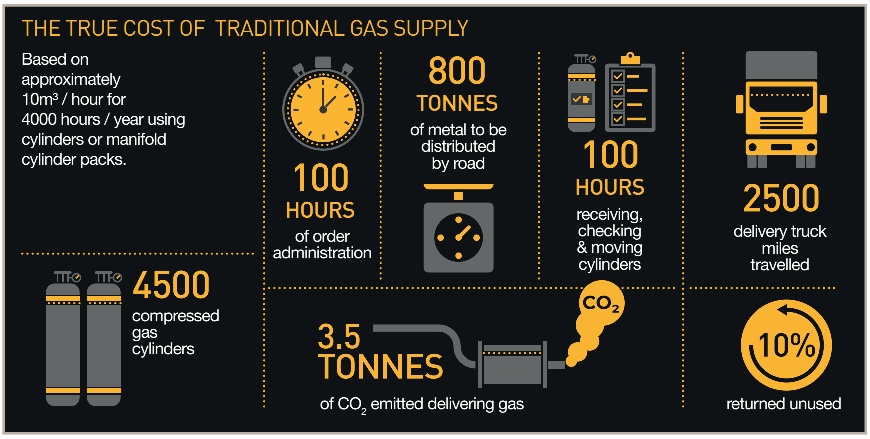
This table illustrates the equilibrium oxygen surface transfer values for water, comparing air containing 20.9% oxygen, in comparison to nitrogen generation, using oxygen partial pressures at the different gas purities.

As can be seen, blanketing water at 4 °C, using nitrogen gas with a maximum remaining oxygen content of 0.5%, the maximum surface transfer of oxygen is 0.313ppm.

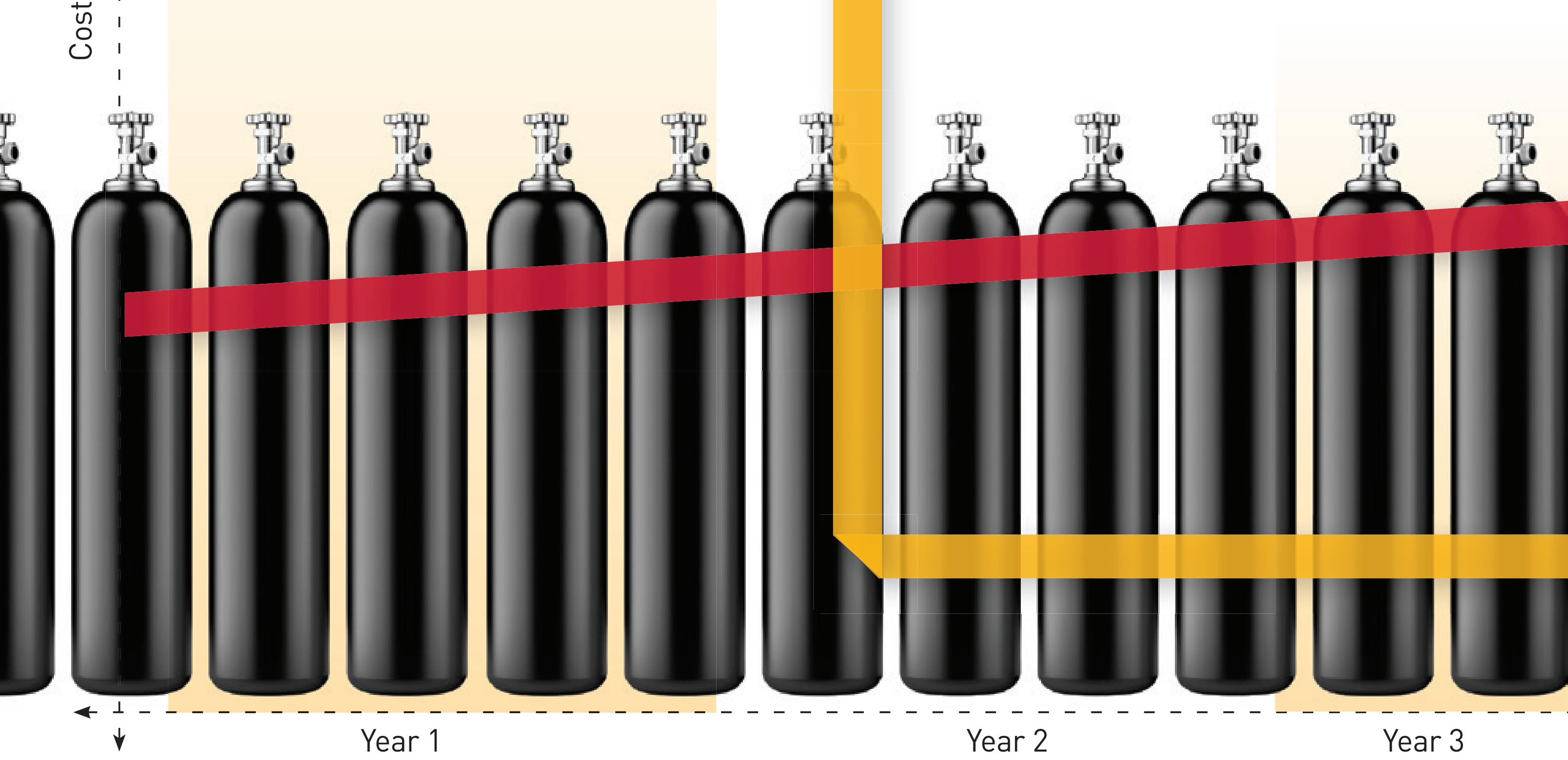
Although beer has many components added to the water base, the expected results would be similar.

Increasing Brewing Efficiency with On-Site Nitrogen Gas Generation

Traditionally, nitrogen and other industrial gases have been delivered to users' sites by gas supply companies, in gas format via high pressure cylinders or liquid via dewars or bulk storage tanks. Now, a more flexible, efficient and economic option is available. On-site nitrogen gas generation produces a continuous supply of ultra-pure, food grade nitrogen from readily available compressed air.



With traditional methods of gas supply, users are responsible for 'hidden extra costs' such as cylinder rental, delivery and administration charges on top of the headline gas price. Additionally, traditional gas supply methods result in waste. Liquid 'boil-off' from dewars vents expensive gas into the atmosphere, and approximately 10% of the gas in every cylinder is returned to the supplier unused. When the true costs are accounted for, on-site gas generation is the most economical source of nitrogen. Subsequently, nitrogen gas generators give brewers control over their gas pressure, purity and flowrate and minimize production downtime due to the permanent availability of an on-demand nitrogen supply.



What Type of Nitrogen Generator is best suited for brewing applications?

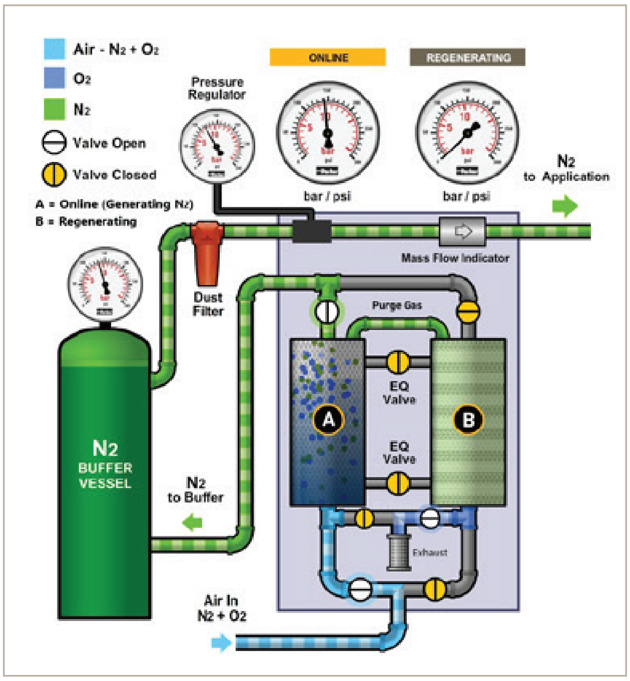
Parker manufacture two methods of gas separation technology – Hollow fibre membrane and pressure swing adsorption (PSA).

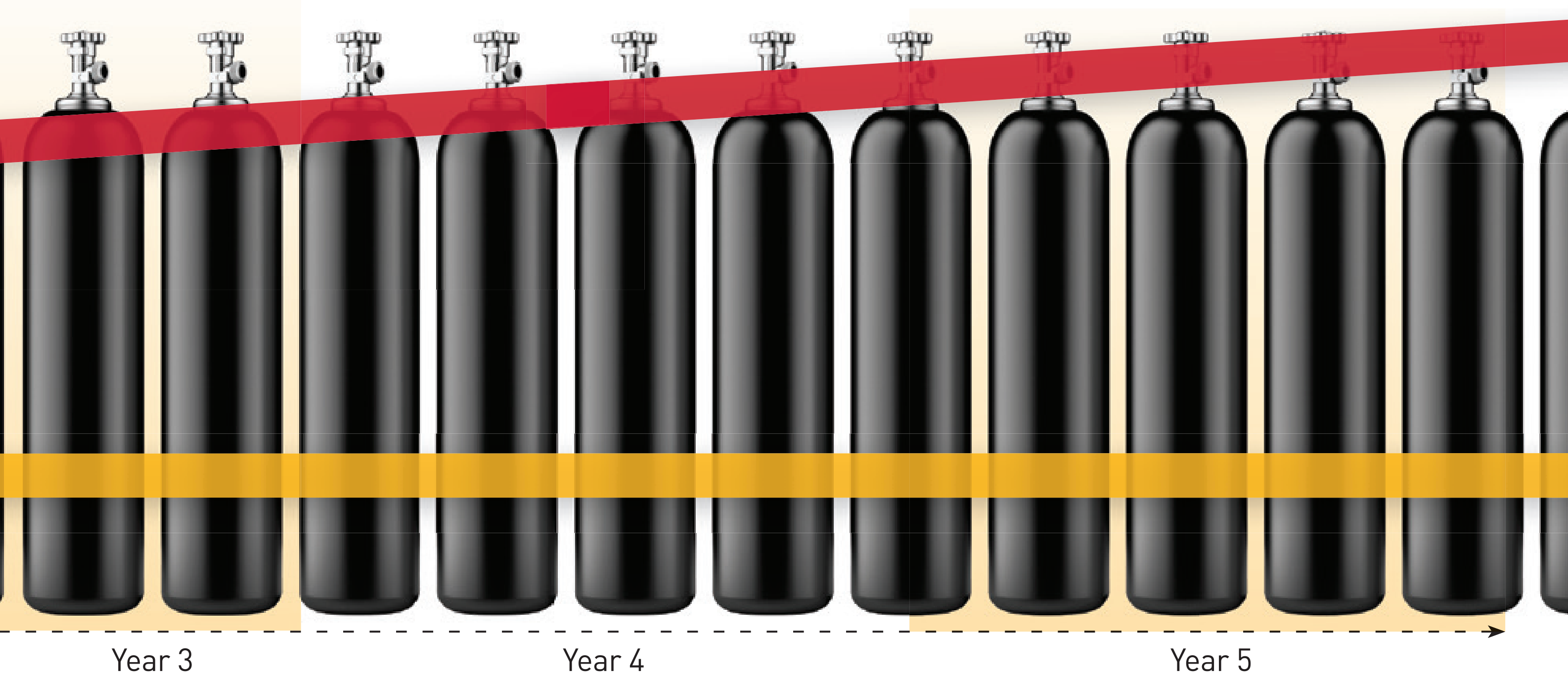
Generally, because of the purity of nitrogen, with regards to maximum remaining oxygen content, required for brewing, pressure swing adsorption is the technology of choice.

Pressure swing adsorption is a method used to separate and isolate certain gas species from a mixture of gases. It is called pressure swing adsorption because the process operates by using materials contained within an appropriate vessel, that selectively adsorb contaminates or unwanted gas species when the gas mixture is pressurised and desorbs them when the gas pressure is released rapidly. Generally, the waste gas(es) are vented to atmosphere through a discharge port and exhaust silencer.

Usually at least two vessels of adsorption materials are used, with one on-line and under pressure adsorbing, the other with pressure released, desorbing and regenerating, ready to change over at prescribe intervals, thus providing a continuous, uninterrupted out-put of the required gas species.

Parker NITROSource PSA and NITROSource Compact are designed to utilise a standard oil-lubricated factory air compressor to produce, independently certified, food grade nitrogen compliant with all global standards.





Quick Study:
Using Nitrogen in Place of Carbon Dioxide

As reviewed, several processes in the production of beer require the use of carbon dioxide (CO_2) and/or inert gases such as nitrogen. Recent carbon dioxide supply issues have highlighted not only the potential risks of relying on outside suppliers to consistently deliver gases when needed, but also the opportunities that exist to use nitrogen instead of carbon dioxide. Unlike carbon dioxide, nitrogen can be produced safely and cost effectively from compressed air, relieving breweries of the need to rely on outside vendor deliveries. In this study, we look at the areas where a brewery can make significant improvements and realize cost savings by using nitrogen instead of carbon dioxide.

Working with a leading brewery, a Parker nitrogen gas generator was used to supply beverage grade nitrogen to various stages in the brewing process. Four specific tests were carried out with the objective of using nitrogen in place of carbon dioxide and evaluating the effects, if any, it had on the finished beer.

Test 1 - Primary Fermentation Chiller Run
Test 2 - Dry Hop Removal Run
Test 3 - Maturation Vessel Pre-Filling / Purging
Test 4 - Secondary or Maturation Vessel Filter Run

The brewery was able to successfully use the on-site nitrogen instead of the vendor supplied carbon dioxide in all tested applications with no discernible effect on the finished beer. The plan going forward is to use generated nitrogen to replace headspace of all vessels and greatly reduce the use of delivered carbon dioxide.

Additional benefits to be potentially gained include:

- Reduced carbon footprint for the brewery (by requiring less tanker delivery of CO_2 dewars)
- Greatly reduce CO_2 vaporization loss and expense
- Minimize vessel turnaround time by reducing time required to vent a tank following a caustic CIP and avoid implosion risk (tank collapse) caused by caustic interaction with CO_2.

Based on an expected annual barrelage of 695,000 bbls, annual savings on purchased CO_2 were over $37,000. Estimated cost to produce the nitrogen gas on-site from an existing compressed air supply is just over $1000.

Key:
bbls = barrels
hl = hectoliter
hl/hr = hectoliter per hour
ppm = parts per million

Test 1—Primary Fermentation Chiller Run

On-site nitrogen gas supply was generated at 0.1% purity (1000 ppm oxygen content) with a flow rate of $25m^3/h$ and pressure of 1.5 bar(g). The generated nitrogen is used to replace headspace and push out 1440 hl of fermented beer from a 2200 hl primary fermentation vessel. The beer is processed through a heat exchanger (chiller) and centrifuge before entering a 2200 hl secondary fermentation (maturation) vessel. Initially, the flow rate of beer varies (approx. 5-20 hl/hr) because of separation of higher solids, but eventually achieves a max flow of ~250 hl/hr for the duration.

In-line dissolved oxygen (DO) measurement was carried out during the last ~100hl of beer from primary fermentation vessel to evaluate oxygen pickup in the beer / headspace interface.

Results
"The tests were successful with negligible dissolved oxygen pickup using on-site generated nitrogen to push out a primary fermentation tank. We were able use nitrogen purity at 0.1% without issue. This is now our standard procedure."

Test 2—Dry Hop Removal Run

On-site nitrogen gas supply was generated at 99.9% purity (1000 ppm oxygen content) with a flow rate of 25m^3/h and pressure of 1.5 bar(g). The generated nitrogen is used to replace headspace and push out 1440 hl of dry hopped beer from a 2200 hl primary fermentation vessel. The beer is processed through a centrifuge before entering a 2200 hl secondary fermentation (maturation) vessel. Initially, the flow rate of beer varies (approx. 5-20 hl/hr) because of separation of higher solids, but eventually achieves a max flow of ~180 hl/hr for the duration.

In-line dissolved oxygen (DO) measurement was carried out during the last ~100hl of beer from primary fermentation vessel to evaluate oxygen pickup in the beer / headspace interface.

Results

"The test was successful with no dissolved oxygen pickup using on-site generated nitrogen to push out a tank for dry hop removal. We were able use nitrogen at the same 0.1% purity with no dissolved oxygen pickup. Again, this is now our standard procedure."

Test 3—Maturation Vessel Pre-Filling/Purging

On-site nitrogen gas supply was generated at 0.1% purity (1000 ppm oxygen content) with a flow rate of 25m^3/h and pressure of 1.5 bar(g). The generated nitrogen was used to pre-fill, or purge, a receiving 2200 hl fermentation vessel and significantly reduce oxygen content.

- Measured oxygen content of the vented air/gas from sample cock of tank, connected to the oxygen analyzer.
- Stop purging when the vented air/gas is at 1000pm oxygen content, before filling vessel with beer.
- During filter run, in-line DO measurement was used to evaluate oxygen pickup in beer/headspace interface.

Results

"We were successful in evacuating the oxygen from the vessels with on-site generated nitrogen before filling with beer. There was no assignable pickup of oxygen in the beer as it was processed to the filter."

Test 4—Secondary or Maturation Vessel Filter Run

On-site nitrogen gas supply was generated at 99.9% purity (1000 ppm oxygen content) with a flow rate of 18m^3/h and pressure of 1.5 bar(g). The generated nitrogen is used to replace headspace and push out ~2100 hl of fermented beer from a 2200 hl secondary fermentation (maturation) vessel, through a filter and into a brite tank.

In-line dissolved oxygen (DO) measurement was carried out during the last ~100hl of beer from primary fermentation vessel to evaluate oxygen pickup in the beer / headspace interface.

Results

"The tests were successful with no dissolved oxygen pickup using on-site generated nitrogen to push out a secondary fermentation tank. Because there is a relatively small head space on the full secondary fermentation tank, we must use CO_2 or nitrogen in this application to avoid dissolved oxygen pick up. We plan to use the on-site generated nitrogen for all tanks sent to filtration."

In Summary

Installing a nitrogen generator allows brewers to take full control of their operations and eliminate potential interruptions (downtime) due to CO_2 supply issues. Several brewery applications are perfectly suited to the use of nitrogen gas and breweries have the added benefit of reduced costs of operation for many years to come.

Typical Onsite Nitrogen Gas Generator Configuration

Compressed air, with a pressure ranging from typically 6-13 bar(g), is generated from an oil lubricated compressor and is stored in a wet air receiver. A wet air receiver can act as a cooling device, reducing compressed air as much as 5°C. This cooling causes condensation of oil and water vapors into liquid oil and water. Unfortunately, it also provides the ideal environment for the rapid growth of microorganisms, especially in the compressor condensate.

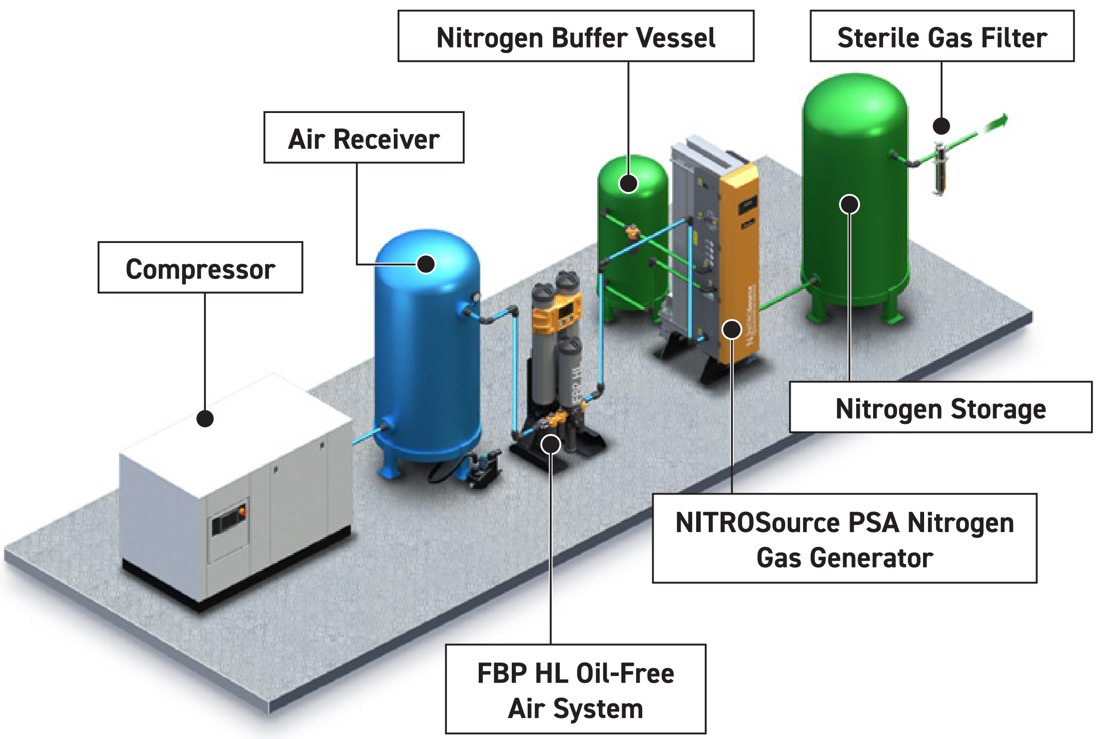
Next, the compressed air flows through a Parker water separator. Water separators are usually the first piece of purification equipment installed downstream of an after-cooler or wet air receiver and should be used to protect coalescing filters from liquid contamination. They will only reduce liquids and will have no effect on water or oil in an aerosol or vapor phase.

Following bulk condensate removal, the compressed air is treated further by a Parker Oil Free Air System. This package consists of dual coalescing pre-filters, a desiccant (adsorption) dryer and a dry particulate filter. The combination of compressed air treatment products on this system reduces particulates (atmospheric dust, rust and pipescale), microorganisms, oil and water aerosols, and water vapor down to a -40°C pressure dewpoint or better. Achieving a dewpoint of 26°C or lower stops corrosion and inhibits the growth of microorganisms, resulting in high quality, food grade compressed air.

The oil-free compressed air then enters the Parker nitrogen gas generator where oxygen and nitrogen are separated by molecular size using carbon molecular sieve. The waste oxygen and other unwanted trace gases are removed and nitrogen gas is output to the application.

The carbon molecular sieve (CMS), is continuously adsorbing and regenerating via a process called pressure swing adsorption (PSA). CMS is not a consumable item and is installed for the service life of the generator which is in excess of 10 years continuous use.

While PSA nitrogen generators can provide nitrogen gas with purities up to 99.999% (10 ppm remaining oxygen content), most food and beverage applications require nitrogen between 99-99.9%. Brewers typically use nitrogen purities between 99.5-99.9%.



In conclusion

On-site nitrogen gas generators have many advantages over traditional nitrogen supplies and are an industry-compliant alternative to users' who currently use nitrogen gas and or carbon dioxide throughout their beer brewing process.

Benefits of Parker on-site nitrogen gas generators:

- Generate food and beverage grade nitrogen gas in accordance with international standards. Including European legislation for nitrogen used as a food additive E941. Ref EU231/2012.
- Produce nitrogen purities of up to 5 ppm maximum remaining oxygen content
- Give users complete control over gas supply and their associated costs – savings often exceeding 70%
- Eliminate multi-year contracts with gas suppliers and unexpected price increases
- Reduce the expense incurred monitoring gas levels, managing supplies, running out of gas and/or waiting for deliveries
- Eliminate gas wasted through boil-off or partially full cylinders sent back to the gas supplier
- Deliver constant flow and pressure 24 hours a day & 7 days a week – ensuring maximum up-time
- Operate from standard factory oil-lubricated air compressor
- Offer fully automatic operation and control
- Are a sustainable, long-life technology
- Reduce your carbon (environmental) footprint
- Lower operating costs and minimize annual servicing which result in very low total cost of ownership
- Offer compact designs – most generators fit through a standard doorway
- Increase safety by eliminating the need to store or handle high-pressure gas cylinders or bulk liquid which, if they leak, can expel asphyxiating gas
- Reduce site vehicle traffic and safety concerns over cryogenic tanker movements
- Eliminate manual handling and personnel competence training for very high-pressure cylinder connection.
- Have established a large installation base with extensive experience within brewing

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