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Criteria for the Selection of the Feed Gas For Ozone Generation

R.J. Horn[1], J.B. Straughton[1], P. Dyer-Smith[2], and D.R. Lewis[2]

[1] Bristol Water Plc,
P.O. Box 218, Bridgewater Road, Bristol BS99 7AU, ENGLAND

[2] Ozonia Ltd.,
Stettbachstrasse 1, CH-8600 Dübendorf, SWITZERLAND

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Abstract

This paper brings together the requirements and experiences of the supplier of ozone generating equipment and the user of this equipment. The technical requirements of the ozone generator on the feed gas, the main characteristics of the system alternatives, the on-site experience and the development of criteria for future applications are described. The particular application of ozone and the quantities required are detailed to provide a full understanding of the background and environment of the case study and its demands on the system selection. The evolution from an air fed system to an oxygen fed system is outlined. This paper describes the joint evaluation of the choice of feed gas for the Purton Water Works by Bristol Water Plc and Ozonia using the experience gained at the Littleton Works and the technical assessment during the pre-contract stage of the Purton Treatment Works Development Scheme.

Introduction

Bristol Water Plc is a water supply company originally incorporated in 1846 as the Bristol Waterworks Company to provide potable water to the City of Bristol which lies between the counties of Gloucestershire and Somerset on the Severn Estuary in the West of England. Since that time it has gone through several changes in its legal status from a regulated (statutory) company under the 1945 Water Act to a public limited company in 1991 following the privatization of the water industry in the United Kingdom. In addition, it has grown to become one of the top four water-only companies serving over 1 million people with more than 340 megalitres of drinking water every day and an annual turnover of £48 million. The area of supply now includes most of the County of Avon, a large part of Somerset and smaller areas of Gloucestershire and Wiltshire.

Two of Bristol Water plc water treatment plants are taken as case studies in this paper, namely the 68 MLD plant at Littleton and the extensions to the 110 MLD plant at Purton. These two works treat water which is abstracted from the Gloucester and Sharpness Canal at Purton. The canal is supplied from the River Severn by pumping at Gloucester.

Littleton Treatment Works (constructed in 1963) was modernized extensively in 1988/9 when two stage ozonization and GAC was introduced (see Figure 1). The full background to the adoption of this process at Littleton was detailed in a paper in August 1990 by Mr. D.J. Smith titled, "The Evolution of an Ozone Process at Littleton Treatment Works" (1) and the experience of the Company during plant design and operation was presented by Mr. R.J. Horn in December 1992 (2).

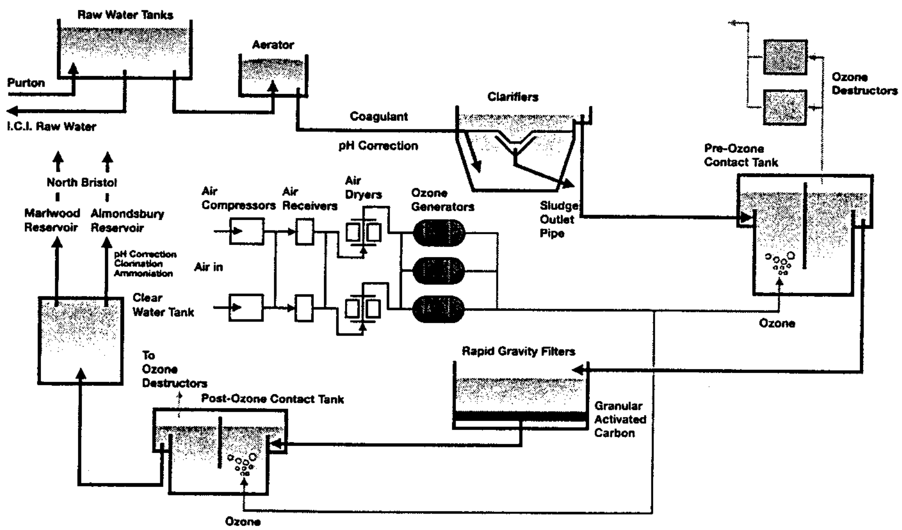

Figure 1. Schematic process diagram at Littleton treatment works.

The introduction of ozone treatment at Littleton followed growing concern over the unsatisfactory water quality from the canal source. Although it fully met the water quality standards, customers in Bristol felt it was less palatable than the water they had received previously. Any change of water source and characteristics is well-known to cause customer complaints, and the change from the traditional Mendip sources to the canal source was no exception to this common experience. However, this was exacerbated by the occasional distribution of unsatisfactory tasting or smelling water. These were classified as earthy/musty arising from metabolic products of algae and bacteria and chlorinous by-products of the disinfection process.

Only limited success followed changes to the treatment process which included the use of powdered activated carbon and the control of the chlorination and dechlorination system. The company's concern led to the consideration of the use of ozone with subsequent desk studies, pilot plant trials and ultimately its adoption (with GAC) at Littleton.

The operation of the company's first ozone plant has achieved the desired improvements in taste, odor and greatly increased customer satisfaction. These improvements since have become statutory requirements for Purton Treatment Works and the company now has the opportunity to use the experience gained from Littleton in its development. The benefit of having two major works using the same raw water has been considerable. It has enabled the evaluation of the process change to be made under "real" conditions using Littleton as a large scale pilot plant!

The company currently has underway a £17.5 million contract for the extension of Purton Treatment Works (increase of 55 MLD) together with major changes to the process to bring it up to the latest standards. This will comprise preozonation (using Ozonia radial diffusers) clarification, rapid gravity filtration, post-ozonation (including hydrogen peroxide dosing), and separate GAC adsorbers (see Figure 2). These will be followed by a final chloramination stage of disinfection. An intermediate pumping station is required because of the hydraulic limitations of the site and the new process requirements. The ozone production (three units each rated at 20 kg/hr) is to use oxygen as the feed gas (unlike Littleton) which will be supplied from an on-site bulk storage and production unit.

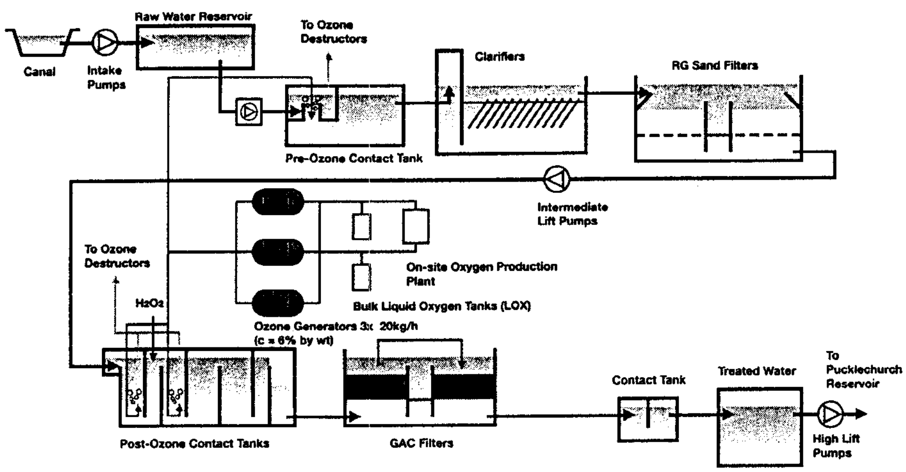

Figure 2. Schematic of the Purton Treatment Works development scheme main process steps (being installed by Degrémont UK).

Importance Of Gas Quality In The Generation Of Ozone

In order to obtain optimal operating conditions, the feed gas at the inlet of the ozone generator has to satisfy the following requirements:

- have a high percentage of oxygen
- be free of impurities which can negatively influence the ozone generation process such as, dust, oil / hydrocarbons and hydrogen
- be dry (max. absolute humidity 0.0000067 kg/kg, corresponding to a dew point of -60°C at 1 bar abs)

- have a low temperature, (max. temperature approx. 25 °C)
- have a pressure high enough to ensure correct operation of the ozone generation and adsorption processes.

The most obvious source for obtaining such a gas is atmospheric air, but as this air does not possess all these qualities, some form of treatment always is necessary.

Two choices are open to the producer of ozone with regard to air treatment.

1. Condition the air such that it meets the requirement specified above, or

2. Separate the oxygen from the air and use it in its pure state.

In ozone generation, the first choice generally is termed an air preparation plant (APP), and the second simply an oxygen supply system.

The Air Preparation Plant (APP)

The main process steps required for a suitable APP are:

- compression
- cooling
- filtering
- drying

For the elimination of undesired impurities such as hydrogen, hydrocarbons etc., each particular case must be considered separately in order to select appropriate technology and equipment. If necessary, a pretreatment plant should be considered, but as these are not common problems, their elimination is not considered in this paper.

Two types of air preparation systems are considered here:

- the medium pressure system (see Figure 3), and

- the low pressure system (see Figure 4).

The medium pressure system operates at a pressure of 5 - 7 bar g and is used for most small sized plants (5 kg O_3/h and less) with an air mass flow rate of approx. 200 kg/h or smaller.

The low pressure system operates at a pressure of 1 - 2 bar g, and generally is used for medium and large size plants (approx. 15+ kg O_3/h).

For ozone plants with a production between 5 kg O_3/h and 15 kg O_3/h consideration of both low and medium pressure systems should be made and an optimization performed to select the best air preparation system for that particular project.

Before the features of the two systems are discussed some considerations about the influence of the main parameters on an APP are considered.

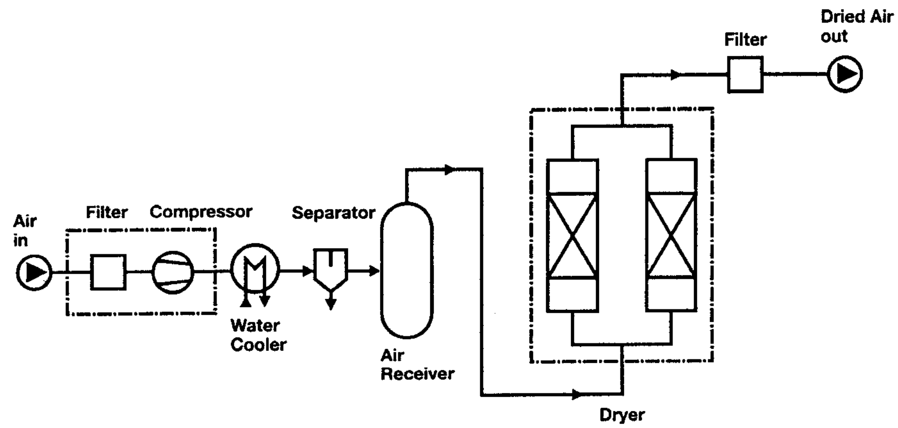

Figure 3. Air preparation plant for ozone generation. Medium pressure, 2-6 bar g.

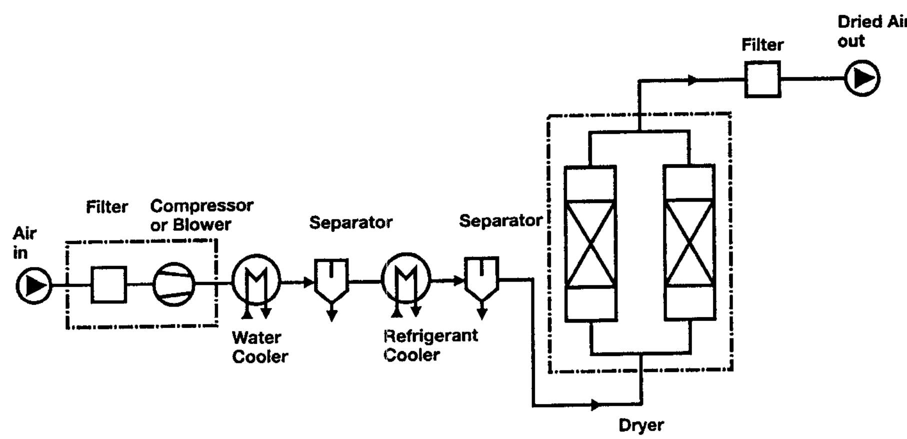

Figure 4. Air preparation plant for ozone generation. Low pressure, 1 - 2 bar g.

INFLUENCE OF PRESSURE AND TEMPERATURE

If the required system pressure is high, then the energy required for compression also will be high and the temperature increase elevated.

For the compression of 1 kg of air from p_{amb} (=1 bar) to an absolute pressure of p_{abs} an energy consumption E_G (kWh/kg) is required and the temperature increase is $\Delta\ t_G$. Here are two examples:

P_{abs} (bar)	E_G (kWh/kg)	Δt_G (°C)
2.0	0.025	100 (screw comp.)
3.0	0.046	170 (screw comp.)

As the saturated water vapor pressure changes with temperature, the amount of water Δx_D (kg/kg) which can be removed from the air by cooling is limited by the absolute humidity x_D (kg/kg) attainable.

In the following table Δx_D has been calculated for different pressures P_{abs} and value of x_{D0} = 0.014883 kg/kg corresponding to an ambient pressure of 1 bar, an ambient temperature of t_{G0}. = 20°C and a relative humidity = 50%.

t_G(°C)	P_{abs} =	2 bar	5 bar
5	Δx_D =	0.01216 kg/kg	0.01389 kg/kg
10		0.01104 kg/kg	0.01335 kg/kg
15		0.00954 kg/kg	0.01276 kg/kg
20		0.00752 kg/kg	0.01196 kg/kg
25		0.00488 kg/kg	0.01092 kg/kg

The above figures show that the removal of moisture is more effective by decreasing the air temperature rather than by increasing its pressure.

Influence of the Absolute Humidity

The size of the dryer is directly dependent on the absolute humidity of the air at the entrance to the dryer. The absolute humidity can be influenced by the temperature and the pressure of the gas as indicated above.

Regeneration Methods of the Dryer

The dryer adsorbent has a limited capability to adsorb water. After reaching the maximum load the adsorbent has to be regenerated. Two methods are available:

- thermal regeneration
- pressure swing regeneration

Thermal Regeneration

With thermal regeneration, the removal of the adsorbed water (desorption) is carried out by heating up the mass of the absorbent and flushing out the water vapor with air. The heating can be carried out by passing the regeneration air through a heater or by using heating elements located in the dryer. This drying method is applicable for a large range of flow rates.

Pressure Swing Regeneration

With pressure expansion, it is possible to remove the adsorbed water (pressure swing regeneration). This method requires a system pressure of at least 5 bar and is not recommended for large plants (above 300 kg/h). Due to the loss of a certain amount of air necessary for the regeneration (15 - 20%), the compressor and the after-cooler have to be sized appropriately.

Medium Pressure Air Preparation

The characteristics of this system are:

- pressure system p_G = 5 - 7 bar
- temperature of air at the dryer inlet t_G = 15 - 25°C
- air flow rate $M_G \leq$ 200 kg/in

The flow sheet (Figure 4) shows a typical plant having the following main items:

Compressor: Oil free reciprocating or rotary piston types are used normally, and they can be either air or water cooled.

Cooler: Water cooling is sufficient provided the cooling water temperature is low enough (approx. 20°C).

Air Receiver: This item is necessary for the discontinuous operation of the compressor.

Air Dryer: Either pressure swing or thermal regeneration.

The air preparation plant installed at the Bristol Water Littleton Treatment Works is a medium pressure plant.

LOW PRESSURE AIR PREPARATION PLANT

The characteristics of this system are:

- system pressure p_G = 1 - 2 bar
- air temperature at dryer inlet t_G = 5°C maximum
- air flow rate M_G >200 kg/h.

The flow sheet (Figure 3) shows a typical low pressure plant. The main items are:

Compressor: Different types of compressors/blowers (oil-free) can be considered according to the air flow rate and system pressure (rotating piston type for pressures up to 1 bar, screw type for pressures above 1 bar).

Cooler: Operated with cooling water. Refrigerant cooler (chilling unit) For temperature reductions to around 5 °C.

Dryer: With thermal regeneration.

AIR FED OZONE PRODUCTION AT LITTLETON TREATMENT WORKS

The ozone plant at Littleton comprises 3 x 5 kg O_3/h medium frequency generators (two supplied in 1989, and one in 1991). These are fed by dry air at 1.7 bar gauge produced from 2 (duty/standby) oil-free rotary compressors (Figure 5).

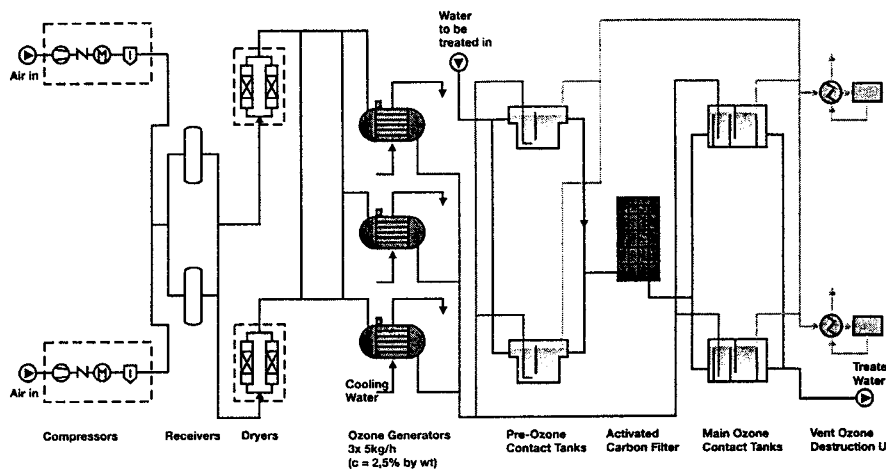

Figure 5. Schematic diagram of Littleton treatment works ozone plant flow.

During the pilot plant trials and investigations phase discussions were held with suppliers and users of ozone plants. Visits were made to the UK and other European operators to obtain guidance on design, performance and installations standards. At this time the use of oxygen was not widespread and the "rule of thumb" was that plant sizes below 80 to 100 kg/hour installed could not justify the use of oxygen because of the additional operating costs imposed, i.e., the cost of supplied oxygen was greater than the financing and energy costs of a conventional air preparation plant. With this background, an air fed ozone plant was proposed for Littleton.

A tender by ABB Industry Ltd. was accepted for a design and construct "package" contract encompassing all civil, building, mechanical and electrical aspects of the ozone application to the existing Works. The contract was executed successfully during 1988/89 and the plant went into operation in May 1989. Performance guarantees were met, the energy consumption being lower at maximum production but exceeded at low ozone production (20% output) due to the compressor element. The original control concept of the air preparation plant (based on experience of pumping and other water treatment plant) was for automatic changeover from the duty to standby stream on "out of limits" condition monitoring. This was not completely realized. The ozone plant was intended to be "stand alone" within the automatic treatment works, and whilst this was achieved, the interaction of the other processes on ozone doses and controls required a considerable learning period. In addition, the variation in raw water quality and the effects of higher than predicted ambient air and water temperatures were greater than expected. This required the operation of both generators and led to a review of the original decision in 1988 to provide no standby generation to reduce the scheme's initial capital cost. The layout and other arrangements made in the original design for a third generator enabled it to be introduced quickly in 1991.

The air preparation plant (compressors, receivers, filters and dryers) has proved to be one of the most demanding and expensive parts of the plant to maintain. This was expected because of the continuous nature of its operation and the need for periodic overhaul, inspection of the compressors and replacement of desiccant and filters, etc. The average annual cost of maintaining the air preparation plant is estimated to be £20,000. This figure has to be an estimated one because maintenance costs are available only for the complete ozone plant, and a number of routine tasks undertaken by shift personnel are not specifically allocated. The achievement of the correct dew point is critical and requires the highest standards of maintenance of the desiccant dryers and associated instrumentation. A number of electrode fuse failures in the ozone generators have been experienced at Littleton, and one possible cause is poor moisture control. Fuses are installed to protect equipment and allow ozone production to continue without interruption, although electrode loss affects the efficiency of the ozone generator and increases power consumption.

The cost of any air preparation plant clearly involves capital, maintenance, operational and energy costs. The initial cost is a consequence of the original decision on feed gas and plant selection and is **not considered** in this paper. The other costs are paramount and comments have been made on maintenance/operational costs. Energy costs are very important with compressors and dryer heaters consuming electricity, however, no significant loss of effficiency has been measured since the plant was commissioned.

In conclusion, and to put the foregoing into perspective, the Littleton air preparation plant has operated well since installation with one major incident which caused the loss of production for a week. It has required a high level of commitment from the maintenance and operational staff to achieve the level of service reached. The introduction of ozone technology to a water company can be a "culture shock" and providing the simplest method of production is one way of limiting the impact on the organization to the essentials concerning the operation and control of the treatment process. The requirement to produce air at low levels of moisture content, oil and dust-free continuously for ozone production is a demanding one.

The experience found from operating an air fed ozone plant for more than four years has provided a better basis for comparison of the alternative feed gases and a clearer understanding of the relevant criteria for the Purton selection. It suggests an "Ideal" feed gas would have the following characteristics:

1. Secure source of supply.
2. Quality suitable without treatment.
3. Easy to control.
4. Low moisture content.

5. No maintenance or operational staff required.
6. Minimum costs.

Features of Oxygen as the Feed Gas

There are several significant reasons for the use of oxygen as a feed gas as an alternative to air:

- The specific energy consumption is cut by more than half.

- The ozone plant becomes smaller and simpler. he size of the ozone generator and the electrical power supply is reduced substantially. No air preparation facilities are required, i.e., no compressors and no drying installation requiring space, maintenance and consuming energy. The reduced gas flow, resulting from higher ozone concentration, makes the vent ozone destruction unit smaller, with a consequent saving in energy. The pipes and fittings also have smaller diameters as result of the lower volumetric gas flows.

- The introduction of even the smallest amounts of nitric oxides in the water is avoided with oxygen. If air is used, the silent electrical discharge produces, besides ozone, a small amount of nitric oxides. In the presence of ozone, these are N_2O (nitrous oxide which is inert), and N_2O_5 (4).

- The simplicity of the plant makes its controls less extensive and therefore cheaper.

- Ozone concentrations of up to 12% by weight today are economically attainable.

- High ozone absorption effficiency at high concentrations are achievable and have been obtained, 95% or more being typical.

- The improved absorption efficiency allows at least a 5% reduction in the installed ozone production capacity to obtain any required dissolved ozone dose in the water.

Oxygen Systems

Today oxygen is a widely used commercial gas and its large scale production, storage and transportation are well developed techniques. The usage of oxygen therefore, for ozone generation, creates no particular problems. There are two possibilities for the provision of oxygen at the ozone generation site:

LIQUID OXYGEN (LOX)

Oxygen is obtained from a liquid oxygen (LOX) reservoir, which is located beside the ozone plant and filled by tanker from a central liquid oxygen production facility. Using a LOX-tank offers various advantages since the installation, operation and maintenance are very simple and it acts as a buffer for the oxygen supply for fluctuations in ozone demand, which are very usual in water treatment plants. It is, therefore, a very elegant method applicable for small and medium sized plants having production rates of up to 50 kg O_3/h.

ON-SITE OXYGEN PRODUCTION

The on-site production of oxygen, generally is by means of either pressure swing adsorption (PSA) or vacuum swing adsorption (VSA) plants for requirements generally above 50 kg O_3/h. Only for very large plants with a relatively constant oxygen demand of a few hundred kilograms per hour can a cryogenic oxygen plant be considered (e.g., Los Angeles, USA) (3).

Oxygen Selection for Purton Treatment Works

The company's success in using ozone and GAC at Littleton for taste and odor improvement naturally led to the decision to use them for the enlargement and process improvements required for the Purton Treatment Works (see Figure 2). This works was subject to an undertaking under the Water Supply (Water Quality) Regulations 1989 to improve the organoleptic quality of the water produced by 1994. The Purton Treatment Works Development Scheme is intended to increase the works capacity by 55 MLD (110 MLD to 165 MLD) and to provide process improvements to meet the current legal requirements for taste and odor, pesticides and nitrates. A Design Brief was produced defining water quality requirements, design principles re standby plant, automation, energy savings etc., and constraints imposed by existing source/effluent disposal limits and operational requirements. Major water treatment contractors were invited to tender design/process proposals for a target type contract on a reimbursable basis for Stage I leading to a Stage II fixed price stage. The design brief did not specify the process stream, or more particularly, the ozone feed gas.

During the Stage I design phase the successful contractor and their ozone sub-contractor proposed the use of oxygen. A joint study then was conducted which included visits to the Zürich Water Supply Works at Lengg and discussions with potential suppliers of oxygen in the UK. Early on in this process it became apparent from the Swiss experience that the use of oxygen to produce ozone could offer a number of advantages.

Further work was conducted to allay Bristol Water plc's concern over security of supply. Talks with oxygen suppliers and visits to their production and distribution facilities led to the decision to evaluate the production of oxygen on-site using a pressure swing absorption (PSA) plant. This further complicated the financial assessment of comparing ozone produced from air with ozone produced from liquid oxygen supplied from bulk storage tanks.

The evaluation also had to take into account:

1. the growth in water production over time, since the full 55 MLD extra capacity would not be used from the first day after commissioning

2. the varying demands for ozone in the preozone and post-ozone contacting It also was necessary to use net present value (NPV) techniques for the financial evaluation to satisfy internal investment appraisal requirements.

In the study a detailed analysis of the various alternative ozone plant layouts was carried out. A total of 18 different options was examined. The six most likely solutions were:

A - Low pressure air fed system
B - Medium pressure air fed system
C - Oxygen fed system with 5 day LOX storage on-site
D - Oxygen fed system with 20 days LOX storage on-site
E - Oxygen fed system with 40 days LOX storage on-site
F - Oxygen fed system with 20 days LOX and on-site production from PSA.

All possibilities were brought to a common basis by performing a NPV (Net Present Value) calculation on the costs of each system. See Figure 6.

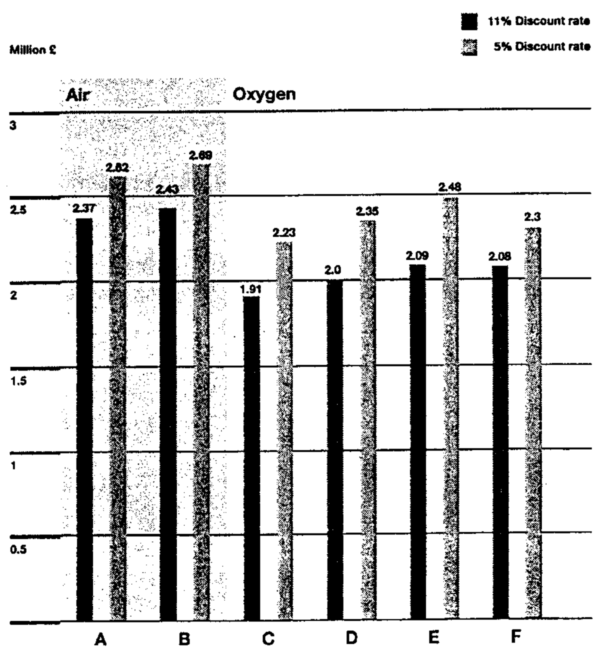

Figure 6. Bristol Water - Purton Treatment Works evaluation of ozone supply options - Net Present Value (NPV-January 1992).

For the NPV calculation the following are the main cost elements:

Water Flow:

- max. design		:	165 MLD
- average flow range			
	in 1994	:	95 MLD
	in 2005	:	140 MLD

Average Ozone Consumption:

	in 1994	:	16 kg/h
	in 2005	:	25 kg/h

Electricity Cost		
Oxygen average prices	:	@ 6.5 t/d = £55-£85/tonne
	:	@ 10.0 t/d = £45-£75/tonne
Time span	:	12 years
Discount rates	:	11% and 5%

Other items in the calculation were taxation and maintenance.

The outcome of the joint assessment was the decision to use oxygen as the feed gas with supplies taken from bulk liquid tanks (LOX) and from an on-site production facility (a PSA/VSA plant), see Figure 7.

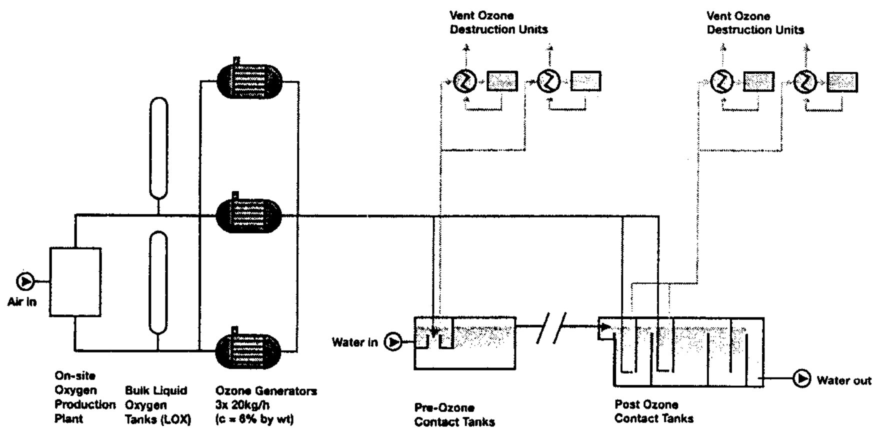

Figure 7. Schematic flow diagram of Purton Treatment Works ozone plant flow.

The latter would provide oxygen at a lower price (depending on its operating level) whilst providing security of supply and a reduction in the number of tanker deliveries. The Purton Works is situated on the edge of a small village through which all traffic to and from the works has to pass, and traffic movements were a particular concern to the local inhabitants during the early consultations period.

Summary

The choice of feed gas for ozone production will be influenced by many considerations depending on the application and the particular circumstances of the user. It is therefore difficult to produce a definitive list of criteria for all situations and perhaps unwise to attempt to do so. However, the identification of the factors considered and methodology used in an actual case may be useful. The purpose of this paper has been to describe the joint approach taken by the user and ozone plant supplier in the selection of the feed gas for the Purton Treatment Works. The close working relationship was in itself an important part of the selection process, and whilst this may be constrained by the need for competitive tendering, it was found to be a most effective and speedy way of dealing with the numerous interacting issues involved. The criteria used for Purton can be summarized as follows:

1. Cost-capital versus operating
2. Quality - purity/low hydrocarbons
3. Security of supply - LOX and PSA/VSA
4. Simplicity - procurement and operation
5. Maintenance demands - resources required (numbers, skills and availability)
6. Environmental disturbance

Future Trends and Developments

Oxygen fed ozone plants are finding a growing application in the ozonation of potable water as a result of the various benefits and advantages described in this paper. Large scale oxygen supply and handling are well established techniques in industry. This readily available supply opens the door for waterworks to produce ozone at low energy consumption, at high concentration with minimal investment cost. To these benefits are coupled a simplified plant operation/ maintenance and improved water quality.

In the future we can expect to see more plants with oxygen being produced on-site. A great deal of development is taking place in the systems for air separation to reduce both energy consumption and investment cost. Coupled to this, air separation plants with much smaller outputs are becoming commercially available. This situation will promote the installation of oxygen facilities comprising a VSA/PSA system for the base load ozone demand with peaks being covered by LOX stored on-site. There also will be a move to the use of much higher ozone concentrations, bringing with it new efficient ozone contact systems. This trend will have a substantial effect on further reducing the cost of ozonation, both in investment and running cost.

A great deal of experience is being gained with oxygen recycle systems. Present economics do not particularly favor the recycle system for water treatment, with the high solubility of oxygen in water, but they are being used at large scale plants, e.g., the paper pulp bleaching industry. Oxygen-fed ozone plants release the user to concentrate his efforts on his primary purpose, for example that of either producing and distributing water or producing and marketing paper pulp.

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Key Words

Ozone; Potable Water Treatment; Oxygen Feed Gas; Air Feed Gas; Activated Carbon, Disinfection; Purton Water Works

Résumé

Cette présentation rassemble à la fois les besoins et les expériences du fournisseur d'équipements de génération d'ozone et de l'utilisateur de ces mêmes équipements. Les spécification techniques du gaz de procédé pour la génération de l'ozone, les caractéristiques des solutions variantes, les résultats obtenus sur l'installation industrielle et l'établissement de critères pour des installation futures sont décrits. Le cas particulier étudie et les quantités requises d'ozone sont détaillés afin de permettre une compréhension complet et les contraintes sur le choix du système. Le passage d'un procédé à l'air vers un procédé à l'oxygène est particulièrement souligné. L'étude présente l'évaluation conjointe effectuée par Bristol Water PLC et Ozonia pour le choix du gaz de procédé sur l'installation de Purton en utilisant l'expérience acquise sur l'installation de Littleton, ainsi que l'assistance technique lors de l'établissement du schema de développement de l'installation de Purton.

Zusammenfassung

Diese Veröffentlichung faßt die Anforderungen und Erfahrungen der Hersteller und Nutzer von Ozongeneratoren zusammen. Die technischen Anforderungen an Ozongeneratoren im Hinblick auf die eingesetzte Sauerstoffquelle, die Hauptcharakteristika der System-alternativen, die Erfahrungen vor Ort und die Entwicklung zukünftiger Kriterien für den Einsatz werden beschrieben. Der definierte Einsatz von Ozon und die notwendigen Mengen werden beschrieben, um zu verstehen, welches System für eine bestimmte Anwendung zu wählen ist. Die Entwicklung vom Luft- hin zum Sauerstoffsystem wird-beschrieben. Die Auswahl der geeigneten Sauerstoffquelle (Luft oder O_2) für ein Wasserwerk durch Bristol Water und Ozonia aufgrund von Vorversuchen im Wasserwerk Littleton wird beschrieben.