



## **Scientific Basis of Newton Gravity Aerator**

The Newton Gravity Aerator is based on over 20 years research by Claude Dyson and a team of researchers at John Moore University in Liverpool. The research focused on air entrainment and oxygen transfer in a Co-Current Downflow Contactor (the technical name for this type of aerator). Two PhDs have been awarded for research peripheral to the design of this aerator for which patents have been granted and others applied for in Europe and USA.

This aerator utilises the impact of a relatively slow speed jet of water flowing down the wall of a tube standing in a greater expanse of water to encapsulate air as discrete bubbles, and to carry the mixture down to the lower end of the tube. Oxygen and nitrogen dissolve from the bubbles into the water during their descent.

### **Focus of Research**

The conditions and criteria for a liquid wall-jet to encapsulate bubbles of gas at impact

The resultant proportions of the gas/liquid mixture

- The velocity of the air bubbles and the actual velocity of the water passing between them
- The impact of the length of the vertical column on oxygen transfer from the gas bubbles to the liquid

### **Research Methodology**

Researchers have found it very difficult to observe and measure accurately what happens when either gas bubbles are moving through a liquid or liquids are moving through a gas atmosphere. The methodology of this research included the design of rigs of varying lengths and cross-sectional areas and water flow rates

Measurements included

Voids Ratio – Proportion of Air in Contactor Column

Air/Water Throughput Ratio

Dissolved Oxygen in the water at inlet and at intervals down the contactor

These measurements were made as the following parameters were varied

- Water Flow Rate
- Wall Jet Length to impact
- Contactor Column Cross-Section
- Contactor Column Length

- Various gases were used, namely Air, Oxygen, and Nitrogen

Radiation absorption techniques were used to estimate voids at depth down the column

The dissolved oxygen concentration in tap-water was measured at points down the column, both using air/oxygen enhancement and nitrogen as purge.

Orifice plates and rotameters were used to measure water flow rates.

## **Research Results**

### **Gas Entrainment**

The volume of air entrained in the water is dependent on length and velocity of the wall jet. For any air to be encapsulated at all it is necessary that the length of the wall jet exceeds some minimum value, but beyond that length, the volume entrained increases with length of jet.

In the initial investigation the jet was projected down a vertical wall, but equivalent conditions were found to be developed if the surface was formed to be initially horizontal, but then to follow a gradually increasing slope.

### **Oxygen Transfer**

As would be expected the concentration of oxygen dissolved in the water increased as the mixture descended the contactor column. This increase was initially rapid, but at a relatively shallow depth the rate of change became much reduced. The final D O concentration attained depended on the D O of the water at entry, but saturation was never reached

This applied both when air or oxygen was the entrained gas and in a reverse sense when oxygenated water was purged with nitrogen..

Water in an initial state of oxygen tension could be oxygenated to show measurable oxygen content.

An increase in the length of wall-jet entrained a greater volume of air with a consequent increase in column voids and greater interstitial water velocity, but did not significantly improve the D O at outlet. Whilst the system could entrain and carry down volumes of air equal to 35% of the water flow, such extreme conditions were not found to be economically beneficial. .

## **THEORETICAL BASES**

The investigations encompassed two areas of science, namely civil engineering hydraulics and basic physical chemistry - disciplines which are not directly related.

Wall-jets can be described as a relatively thin sheet of water flowing down a plane vertical surface. They are of little apparent importance, and their air entraining properties have been reported only when used as modelling aids in the design of civil engineering schemes for water conveyance.

### **Flow Criteria**

A theoretical analysis of the flow patterns generated by a swarm of bubbles rising through a confined body of water has been presented by Nicklin, whose theory was extended by Whillock and Thorn, and subsequently confirmed experimentally by Tibke as part of these investigations.

The proportions of the air/water mixture generated by a wall-jet, and the actual and relative velocities of the individual phases necessary to sustain a stable flow regime down a vertical shaft could now be estimated.

Where a jet of water passes through the atmosphere and then enters a body of water as at a water-fall, air is introduced and bubbles formed, which usually rise quickly to the surface. An investigation by Ervine measured the total air drawn in by jets of rectangular section with entry velocities up to 9 m / s. This showed that at high velocity equal flow rates of air and water was easily achieved. A further conclusion was that some of this air drawn in was adhering to the surface of the jet, a conclusion reached by Quick and many other researchers.

Wood and Ackers suggested that air would only be entrained on a spillway beyond the "critical point", defined as the point at which the boundary layer had grown through to the surface.

These investigations had been instigated to co-ordinate the results of scale model tests performed at Froude criteria which involved the behaviour of wall jets down a vertical face. It was confirmed experimentally that a jet could only entrain air when it had been developed by accelerating some minimum distance down a vertical wall. This was shown analytically to be the distance necessary for the growth of fully turbulent conditions within the jet, which is in agreement with Wood and Ackers.

Over all it has been proven by many reputable researchers that it is essential that the face of an impinging jet has to be rough in order that air can be drawn into the surface of the standing water where bubbles will be formed and that this is dependent on the growth of the turbulent boundary layer.

Clearly impinging jets under suitable circumstances can entrain equal volumes of air but the subsequent behaviour of the mixture of bubbles in water depends on the physical constraints imposed by the plan area at entry. For a small jet projected into a large pool immediate separation occurs and the bubbles escape, but when a large high speed jet is projected into a small tube mounted vertically a large proportion of the bubbles formed is carried down.

Nicklin showed that although the velocity with which a solitary bubble rises in still water can be estimated using Reynolds criteria and viscous theory, a different analysis is necessary when a swarm of bubbles is rising in a confined space or tube. He argued that the introduction of air into such a column increased the total volume, and as bubbles ascended water must descend.

The relative or slip velocity of the water passing between bubbles is shown not to be equal to the rise velocity of a single bubble and the situation is further complicated if the whole mass is falling or rising. Thus co-current or counter-current flows will develop, cases and analyses of which are given by Wallis and in UKAEA publications.

Interest was mainly on the behaviour of pockets of steam generated on the walls of heat exchangers.

Chemical engineers also have reported two phase flow evaluations, but these generally were instances involving small bubbles or viscous fluids as an aid to some process or reaction. The behaviour of the larger bubbles (c 4mm) generated naturally and hence related to the surface tension of clean water is of limited interest in itself, and the investigation by Tibke into the co-current downflow was related to model

testing of air entrainment in vertical shafts as an aid in the design of civil engineering structures in bulk water transfer schemes.

The flow rates of air and water were measured in shafts of a range of cross-sections, and the voids content in the descending column estimated by Gamma ray absorption techniques, so enabling the absolute velocity of individual phases to be calculated. These results confirmed Nicklin's hypotheses as extended, and enabled the non-linear relationship between air and water velocities to be evaluated.

### **Gas Transfer**

The Two Film Theory which is developed from Fick's Law of Diffusion is accepted as a valid interpretation of the manner in which a gas dissolves into a liquid. The theory reasonably postulates that the mass of gas crossing the interface depends on the contact area, the contact time, the driving force, which is defined as the difference between the saturation concentration at the interface and that in the bulk of the liquid and the diffusion coefficient.

Most systems which use air to rise under buoyancy inject it in the form of small bubbles which exhibit a great contact area (specific surface) and rise slowly to the surface. Two specified criteria are thus satisfied, but the dissolved gas concentration at the interface and in the adjacent liquid is impossible to confirm by measurement, nor is the Diffusion Coefficient  $K_L$ .

A view which has recently gained credence argues that this Coefficient depends on the degree of turbulence in the liquid abutting the interface, thus enhancing mass transfer across it.

Researchers over more than 70 years, notably Higbie, Passveer, and Coppock and Maklejohn have argued such variation exists, and analysis of the results of these experiments substantiates their opinions.

The dynamic method used to test diffused air systems for waste water treatment involves evaluating the well known  $K_L a$  factor which incorporates specific surface and  $K_L$ , and which strictly only relates to the set of circumstances under which it was evaluated.

## **RESEARCH FINDINGS**

The investigation into the oxygen transfer potential of this downflow system initially used a contactor column of 68 mm diameter and 2.5 m tall suspended inside a glass reactor column of 150 mm diameter. Water collected from an overflow was then pumped to a reservoir and recycled back through the contactor.

Recovery of water purged with sodium sulphite was rapid, so a more reliable method using a flow of sulphite at a known strength was fed into the pump at a uniform rate and the D O concentration recorded when steady state conditions had become established.

Using a similar column approximately 4 m tall clean tap water was passed through to waste at various flow rates, and D O concentrations at several tapping points down the column were noted, using air, oxygen, and nitrogen as entrained gases. As with all the investigations the gases were induced solely by the entrainment action of the wall-jet, compressors being unnecessary.

Operation of this downflow contactor using air and clean water generates a natural spectrum of bubbles about 4 mm diameter which, when combined with the column voids ratio, enables the contact area to be estimated. Combining results of oxygen transfer rates from more than 50 tests with the relationships between voids, throughput, flow rate and relative velocities established by the entrainment series, it was shown that  $K_L$  is a function of the interstitial slip velocity.

At an area of contact between a gas and liquid molecule, each will migrate across the interface until the liquid is saturated with gas and the limiting vapour pressure is attained in the gas.

In this co-current downflow system oxygen and nitrogen will migrate at rates determined by the difference between the saturation concentration at the interface and the concentration already existing in the water, and the rate at which these gases diffuse will depend on their partial pressures in the bubble, which will change because their relative proportions change by depletion, as the bubbles move down the column.