Manufacturing High Quality Rotating Biological Contactor's for the UK Water industry

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Abstract

The principle of the Rotating Biological Contactor (RBC) was originated in the early part of the century and today there are many thousands of units operating world wide. However, the RBC has been plagued with mechanical deficiencies since its conception. This paper presents a brief insight into some of the major mechanical defects associated with RBC's. These findings have been documented as part of the largest mechanical survey of operational RBC units ever undertaken. Having the benefit of a thorough understanding of the mechanisms and reasons for mechanical failure, a new approach to designing RBC's is discussed. This has resulted in Water companies and independent operators seeking a new generation of RBC with a guaranteed operational life of twenty years. Furthermore, it displays the benefits of Academia working in partnership with Industry to produce low cost, high quality equipment.

The manufacture of the 'Cranfield' designed RBC unit is undertaken by Copa Ltd. The design offers a twenty year warranty and is currently supplied to a few of the major Water companies in the United Kingdom. This warranty is unique within the United Kingdom Water Industry where guarantees of 3 to 6 years have previously been provided by manufacturers of water industry plant.

Introduction

The principal of the Rotating Biological Contactor (RBC) was first developed in the late 1920's (Doman, 1929), however, it was not until the 1960's that the first commercial system was installed in West Germany (Tchobanoglous, 1990; Gray, 1989). Thereafter, the popularity of RBC's grew and they are currently operated worldwide. The RBC is primarily used for sewage treatment in small communities, though it is now being used for larger treatment operations (Findlay et al., 1998). They consist of discs attached together to form a media pack as illustrated in figure 1. The polymer discs, also referred to as media panels, are held within an enclosed basin, submerged by approximately 40% of the surface area. Wastewater passes through the basin as the disks slowly rotate, at approximately 1 rev/min, exposing the biological growth (biomass) alternately to the wastewater, and to the surrounding air. The RBC operates continuously throughout its life, any break in operation will necessitate attention by the operator to maintain imposed consent standards. Typically, a media pack consisting of a collection of media panels, represents one stage of the treatment process. The RBC can consist of up to four or even five separate media packs depending upon the population served.

Figure 1 Typical Rotating Biological Contactor

Whilst it is recognised that the RBC is effective for sewage treatment, several Water Companies in the U.K and abroad, have experienced mechanical failures well before their expiry dates. This results in the user adopting an alternative treatment method and /or redirecting the sewage liquor whilst the plant is out of operation, at an additional operating cost. An in-depth investigation by the U.S Environmental Protection Agency (Brenner) into the design, operation and maintenance of RBC's, concluded that whilst improvements in the design of RBC's can result in more robust units, the loss of mechanical integrity of these units is common and unpredictable. In a separate report Weston stated: *"It is recommended that design engineers should seek an RBC equipment warranty of sufficient duration and scope to protect the owner from failure. It is the opinion of the authors that equipment manufacturers would eventually solve the equipment problems."*

These findings were reiterated in the largest survey on the mechanical integrity of operational RBC units ever undertaken (Mba et al.). Typical failures reported by Brenner and Mba included shaft breakage, stub shaft damage, media degradation and damage, media support structure fracture and degradation, and bearing failure. Any one, or combination, of these faults will require prompt replacement of the failed component.

Brief description of mechanical deficiencies associated with the RBC.

A mechanical survey of over two hundred and fifty operational RBC's highlighted several common mechanical deficiencies, which are detailed as:

I Shaft failure

Shaft fracture has been experienced on several RBC's, resulting in complete collapse of the unit. This mode of failure is considered to be the most severe form of mechanical breakdown, due to total replacement costs.

II Media Support Structure failure

The RBC media support structure generally consists of between four to twelve equal segments which are contained within a common frame, dependent on the size of the RBC. Each individual segment is usually supported by three through rods attached at their ends to a supporting structure. Fatigue failure of this structure has been experienced, particularly on the larger RBC's, see figure 2

Figure 2 Damaged media support structure

Many RBC's employ 'U' shaped bolts, or straps, to clamp the media supporting rods onto the supporting structure. It is common for these bolts/straps to suffer from fatigue fracture, particularly on the first and second media pack where the biomass loading is greatest, see figure 3.

Figure 3 Fractured 'U' strap

In addition, clamps securing the through rods to the supporting frame have in many instances lost their clamping efficiency, as a result of inadequate design. In several instances this has resulted in the through rod becoming loose and moving axially along the length of the rotor, eventually catching the concrete or GRP basin/tank, resulting in major damage, see figure 4.

Figure 4 Loss of clamping efficiency resulting from a fractured ‘U’ strap

IV High density polypropylene media panels

Tearing, loss of rigidity and crumbling of these media panels are common and highlighted in figures 5 and 6, depicting mechanical inadequacies in designs of media panels. Tearing generally occurs in the region through which the support/through rods pass and is attributed to Hertizan stress concentrations in the vicinity of the through rod hole. In addition, poor quality of finish during manufacture results in the creation of jagged edges giving rise to stress concentrations, which eventually lead to crack growth and tearing in this vicinity, see figure 7.

Figure 5 Tearing of high-density polypropylene media panels

Figure 6 Loss of media pack due to tearing of HD polypropylene media panels

Figure 7 Stress concentrations on the media panel

IV Inadequate locking of nuts and bolts

Looseness of nuts and bolts is very common on RBC's. A common form of locking is the application of a nylon-locking nut; however, these have also been known to become loose. In addition, where differing materials have been employed on the media support structure and retaining bolts, plastic washers have been used to separate these materials in an attempt to avoid galvanic corrosion. However, with time the plastic washers creep, leading to loss of tightening torque, see figure 8.

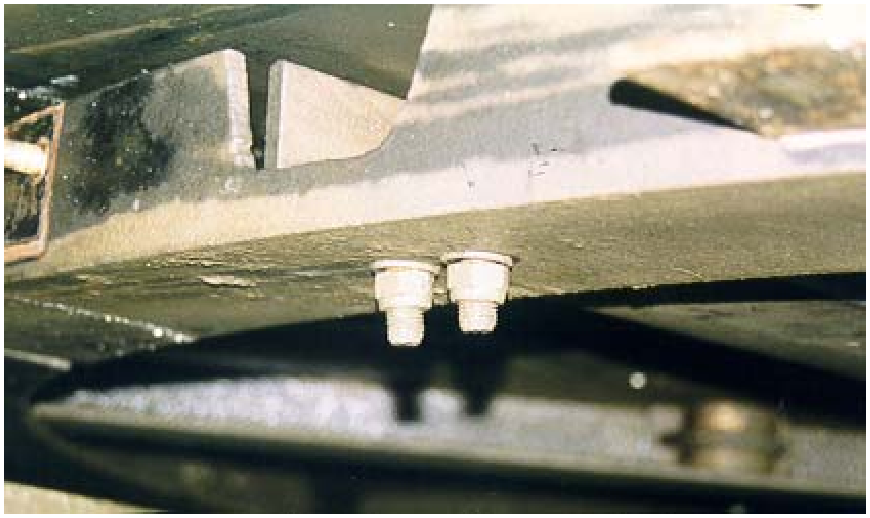

Figure 8 Loose clamping bolts

V Others

Bearing failure are very common on RBC's and can result in loss of operation for up to two weeks, depending on severity.

The most influential factor affecting the life of RBC units, particularly the shaft and media support structure, is low frequency corrosion fatigue. Further details of the reasons of such defects have been detailed by Mba et. al.

The new design

It is shown that the evolution of mechanical design of RBC's has largely been directed by economies of manufacture and operational requirements. However, the advances in the mechanical design of the RBC supporting structure is largely influenced by overcoming known mechanical deficiencies as well as increasing operational life. This section depicts the current technology and practice of UK based manufacturers.

Before attempting to design any machine component, it is most important to understand the mechanism by which the component is subject to force loading, and whether the loading is static or cyclic. For example, on most medium size RBC's the media segment is supported by three through rods, whereby each rod is reacted back onto the media support frame and held in position by some form of end clamp. When establishing the magnitude of loading applied to each of through rods per media segment, it is a common misconception to assume that each through rods supports the same load and that the loading is constant. Unquestionably by making such an erroneous assumption can result in premature failure of the through rod and rod end clamp.

The actual load value is dependent on the type, size and orientation of the media corrugations, moreover, the loading is "dynamic" resulting from rotation. For example, as the media emerges from the liquor, draining off water has to be considered in addition to the biomass loading. Furthermore, as the media segment re-enters the liquor the loading has now changed both in magnitude and direction, thereby causing reversed cycle loading, which is an important factor when selecting the size of through rod and rod end clamp design. By undertaking a finite element analysis, it has been shown that as a consequence of the corrugations, one of the three through rods will be subjected to a much higher load value, compared to the other two rods supporting the same media segment. This is probably why tearing of the media in the vicinity of the through rod hole always occurs at the one hole before progressing onto the next.

Identifying which of the through rods is subjected to the highest dynamic loading, and by taking cognizance of the design employed for the media pack support frame, the size of rod can be established.

However, it is important to acknowledge that for each rotation of the shaft, the through rod end clamp has to sustain both direct loading combined with bending couples, moreover, the direction of the load experiences a 270 degree change in direction. This change in direction also causes the through rod to rotate if the ends are not rigidly clamped. This phenomenon of rod rotation has been observed on many RBC's. Therefore, the most efficient method of securing the through rods to the media pack support frame is to offer clamping rigidity for the 270-degree change in load direction.

Different manufacturers approach this problem in a number of ways. The approach embraced by Cranfield University, is to provide a four point, line contact, method of support by employing a double "vee block" design illustrated in figure 9. Furthermore, the wall thickness of the through rod has to be sufficiently rigid so as not to allow crushing of the tube wall, therefore the tightening torque of the clamping bolts is also part of the design specification, together with the axial length of the vee block. Best practice relating to the design of through rod end clamps is governed by the design of the media pack support frame, moreover, most manufacturers acknowledge the loading pattern described above will give rise to bolt loosing. Therefore positive mechanical bolt locking is highly recommended.

Surface protection of the through rod is also an important consideration when studying the fatigue life. For example, galvanising can reduce the expected service life. This is because zinc has a lower fatigue strength than that of hot rolled steel tubing and micro cracks in the zinc can propagate into the steel substrate thereby reducing the expected services life.

Over the period of investigation experience has shown that all RBC components have experienced fatigue failure, thereby suggesting that the designers have used inappropriate fatigue data. To achieve a twenty-year operational life, with a biomass loading equivalent to 5mm thickness on the inlet media pack, the following design criteria have been proposed (Mba et. al)

a. Stainless Steel should not be used on future RBC's.
b. Polymers must not be subject to compression or tension strengths above 4MPa.
c. Stresses within the frame and shaft must be subject to a limiting bending stress of 20 MPa.

Figure 9 Four point line contact 'vee' block

Furthermore, to combat loss of bolt tightening torque use is made of positive locking for both nuts and bolts, see figure 10. Initial difficulties of properly aligning tab washers has been over come by pre-forming the washer on a jig there by ensuring the "upturned" section always aligns with the flat of the nut or bolt.

Figure 10 Use of positive locking plates on nuts and bolts

To overcome this problem, the particular region has been strengthened and more stringent finishing requirements are requested, sees figure 11. Furthermore, it was noted that the thickness of high-density polypropylene employed (0.5mm) was insufficient to avoid tearing and retain rigidity. An increased thickness of 0.9mm is currently successfully employed.

Figure 11 Strengthened ring on media panel

In addition to the normal design specifications it is strongly advised care must be exercised to ensure that stresses are not induced during manufacture or at installation due to misalignment. Any misalignment would result in raised stresses beyond the permissible fatigue stress limit. It should be noted that clamping the through rods to the frames avoids stresses been raised to manufacture

Conclusion

The mechanical design of an RBC is not simply concerned with the corrosion and fatigue behaviour of the various materials chosen at low speeds of loading, but also understanding the dynamic loading on the structure and bolts. Failure to understand these requirements is probably why so many failures have been experienced after the unit has been in operation only a few months or years of service. As a direct result of the research discussed in this paper, a mechanical specification for all RBC manufacturers has been established

As a result of the Cranfield initiative, not only is the failure mode of RBC's fully understood but it is now possible to purchase an RBC warranted for 20 years, meeting the 'Weston' criteria. These design improvements are incorporated in the RBC's manufactured by Copa Ltd.

Acknowledgements

Mr. G. E. Findlay would like to thank Mr Michael Froud, Managing Director, Copa Ltd, for his support and commitment.

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