THE GENESIS AND EVOLUTION OF ACTIVATED SLUDGE TECHNOLOGY

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INTRODUCTION

The design and operation of activated sludge systems represents one of the key topics covered during any environmental engineer' s education. Our courses and textbooks thoroughly examine the topic, shedding light and wisdom on a process whose finer details have been mastered to a point likely more advanced than that of any other wastewater treatment technology.

However, should you happen to ask any one of our student' s what they know about the formative history of the concept, let alone the names and backgrounds of the responsible engineers, you' ll quickly find that their corresponding knowledge ranges from bare to nil. In large measure, the technical roots for activated sludge have largely been ignored within our current texts and classes, such that most students likely share a common misconception that activated sludge has forever been the preeminent option for wastewater purification.

Most practicing engineers, though, belatedly develop an appreciation for the 'art' of their applied technology, transcending their textbook's wisdom about kinetics and microbiology with a personal, human interest in the '*who, what, when, and why*' of the affiliated history. This article will consequently examine the yesteryear circumstances under which activated sludge was devised, and the early developments which largely shaped its subsequent use.

Admittedly, there have been many articles written about this singular topic. The following chronology provides a summarial overview of these prior 'review' publications: *Porter, 1917; Ardern, 1917; Porter, 1921; Martin, 1927; Clark, 1930; Mohlman, 1938; Greeley, 1945; Sawyer, 1965; and Alleman, 1984.*

These works have progressively provided informative reviews and updates on the ever-expanding history of activated sludge treatment. Porter's two works alone, respectively written in 1917 and 1921, are certainly indicative of the explosive interest which this technology first drew. Barely six years after the idea had originally been published, the associated literature had already grown in number to nearly 800 articles. The paper at-hand will, therefore, unavoidably retrace technical developments thoroughly documented by these preceeding activated sludge historians. This latest review will, however, attempt to provide yet another slant on the topic, with new insights regarding the personal and scientific motivations which catalyzed the original concept.

FLEDGLING CONCERNS ABOUT WASTEWATER MANAGEMENT:

Mid-to Late-19th Century

In order to understand the impact which activated sludge had on wastewater treatment technology, one must first appreciate the relative infancy of the 'sanitary' field which existed during the mid- to late-1800's. Midway through the 19th century, barely a handful of European cities had any sort of organized approach to handling their daily wastewater problem. While the Industrial Revolution had produced a manifold range of technical blessings, these new industries also added a considerable increase in the magnitude and strength of local waste output, heavily befouling their already burdened environment.

Installing sewers would prove to be the first step in the sequential process of waste management, but very few cities had yet made this effort. The necessary technology had been established nearly two millenia earlier by Greek and Roman planners, but for most industrialized 19th century towns the notion of intentionally conveying these wastes streams beyond their municipal borders was still in its infancy…and effectively beyond their technical capabilities. For this matter, the delivery of clean water itself had hardly become a commonplace practice.

Lacking any means of collecting and removing these wastewaters, therefore, the convenient solution was either one of direct discharge from chamber pot to street or, for those more affluent homes, to rely on a central cesspit. However, John Snow's investigation in the 1850's of yet another cholera outbreak caused by one such cesspit failure (i.e., near London's Broad Street area) provided a frightfully compelling motivation to find suitable solutions for the public's intertwined water/wastewater problems.

Over the next several decades there was a consequent move to install pumping and supply systems for delivering clean water, followed shortly thereafter by complementary sewer networks with which this incoming water could then be removed to some distant point of discharge. The science of sewer design, though, was anything but a mature technology. As implied by the classic 2858 ‘Punch’ poem, "*Slow But Sewer*," there was considerable argument about the notion of co-mingling rain waters to flush and dilute these streams, but the problems created by inadequately sloped sewers eventually led to widespread adoption of the combined designs.

At this point, the solution of downstream ‘dilution’ had become civilization’s best strategy for dealing with wastes. However, with these wastes now being funneled to discrete outfalls, the idea evolved that these streams might actually be used for beneficial gain as a convenient, and free, source of fertilizing nutrients. Punch’s poem briefly captures this mood, and Victor Hugh’s classic, "*Les Miserables*," offered an even more convincing argument for reusing what he aptly described as the ‘*detritus of capital’*:

"A great city is the most powerful of stercoraries. To employ the city to enrich the plain would be a sure success. If our gold in filth, then our filth is gold….these fetid streams of subterranean slime which the pavement hides from you, do you know what all this is? It is the flowering meadow, it is the green grass, it is marjoram and thyme and sage, it is game, it is cattle, it is the satisfied low of huge oxen at evening, it is perfumed hay, it is golden corn, it is bread on your table, it is warm blood in your veins, it is health, it is joy, it is life."

These newly devised waste conduits were subsequently recognized as a prime commodity for entrepreuneurial gain, and a cottage industry of wastewater alchemists quickly emerged intent on extracting the nutrient essence of sewage for monetary gain. The Native Guano Company eventually dominated this ‘manure’ market in England, franchised and licensed to cities with the lofty expectation that they could transform their foul wastes into a profitable ‘artificial fertilizer.’ In retrospect, therefore, these original treatment plants were frankly not built for environmental or sanitary gain. Instead, the prime goal for this company’s patented technology, known as the "ABC Process,’ was considerably more focused on nutrient recovery (nitrogen and phosphorus).

In retrospect, though, the ABC Process started a sanitary revolution whose technical prodigy would eventually lead us to full-fledged wastewater treatment facilities. This original procedure, using alum, blood, and clay (i.e., "ABC") to optimistically promote a sort of natural ‘coagulation,’ no doubt qualifies as the seminal prototype for physical-chemical sewage treatment. Undoubtedly, this scheme was a maloderous first step, but the precedent had been established against which future engineers could measure their success.

EARLY BIOLOGICAL WASTEWATER TECHNOLOGY:

1870’s -> 1900’s

Biological treatment was unquestionably a primitive science in the late 1800’s, having only recently been elucidated through progressive European (i.e. Mueller, Frankland, Bailey-Denton, Dibdin) and American (i.e. Mills, Hazen, Drown and Sedgwick of the Lawrence Experimental Station situated in Lawrence, Massachusetts) filtration research. (Peters & Alleman, 1982) The basic derivatives of their work included intermittent filters, contact beds and trickling filters.

Septic tanks were also popular during this era, at least until Cameron obtained a restrictive patent in 1896 and began to enforce substantial royalty charges despite bitter public criticism. Although the popularity of septic tanks subsequently faded, alternative anaerobic systems were soon available, including both the classic Imhoff Tank and its predecessor, the Travis 'Colloider' or 'Hydrolytic' Tank. (Peters & Alleman, 1982) Imhoff also patented his unit, but the associated royalty charges were considerably lower.

PRELIMINARY 'BLOWING-AIR' RESEARCH:

1880's -> 1910's

Searching for an improvement in sewage treatment, and with an intuitive inclination that aerobic conditions would avoid undesirable, malodorous anaerobic results, several researchers began to explore blowing air into sewage tanks. Dr. Angus Smith's work in 1882 is commonly referenced as the original study, followed by Dibdin and Dupre, Hartland and Kaye-Parry, Drown, and Mason and Hine. (Martin, 1927; Pearse, 1938) For the most part, these early pioneers felt that oxygen presence '*per se*' would provide the desired oxidation of wastewater contaminants. Experimental results, though, were nominal at best. Although putrescence was typically delayed, the effort and expense of aeration seemed to lack significant compensation in terms of improved treatment.

Somewhat greater success was obtained, however, in studies of artificially aerated contact filter beds conducted both by Col. George Waring and the Lawrence Experimental Station. (Martin, 1927; Pearse, 1938; Peters & Alleman, 1982) In hindsight, it is evident that these latter fixed-film units were receptive to the stimulus of aeration because of their existing biomass, whereas the earlier aeration tanks lacked a recycled biological population.

Over the course of the next few years, the importance of a suspended precipitant for enhanced biological treatment became more accepted. Studies conducted by Mather and Platt in 1893 indicated that precipitated impurities which accumulated at the bottom of aeration tanks provided a marked enhancement of available treatment. (Martin, 1927) In his presentation to the Royal Commission in 1905, Adeney reinforced this belief that collected humus matters would accelerate the treatment capacity. (Martin, 1927; Pearse, 1938) Fowler's experiments on sewage aeration in 1897 also yielded a clear effluent with rapid settling deposits of particulate matter. (martin, 1938) However, Fowler conversely viewed the enhanced deposition as a failure since he personally believed that sewage impurities were to be rendered soluble or gasified for optimal treatment.

By 1910, the merits of aerating sewage in the presence of biological humus or slime were beginning to find widespread acknowledgement. In their classic full-scale New York study, Black and Phelps decided to abandon coarse rock media in favor of closely spaced, wooden laths in order to achieve a higher surface area for desired slime accumulation. (Black & Phelps, 1914) In essence, their unit was an aerated version of the prior Travis 'Colloider' or 'Hydrolytic' Tank (which had also used wood laths, but in an anaerobic contact chamber).

Clark and Gage also initiated similar laboratory studies at Lawrence in 1912, comparing aerated treatment efficiencies of bottles inoculated with algal suspensions against that obtained in packed slate beds. (Martin, 1927; Pearse, 1938) The slate bed concept should, however, be attributed to Dibdin. (Dibdin, 1913) Having been unsuccessful at simple aeration in 1884, Dibdin had successively studied intermittent filtration, contact beds and serial contact beds before coming full circle to the notion of combining aeration with biological treatment in a slate bed contactor.

INITIAL GENESIS OF THE ACTIVATED SLUDGE CONCEPT:

1912 -> 1914

Giving these latter studies at New York and Lawrence,it was, therefore, serendipitous that the emminent Englishman, Sir Gilbert John Fowler, was called to the United States to review the New York Harbor pollution problem. (Martin, 1927; Pearse, 1938; Ardern & Lockett, 1914a) In conjunction with this trip, Fowler had an opportunity to witness first-hand Clark and Gage' s ongoing experiments on Lawrence in 1912. Fowler subsequently credited this visit as the impetus for his "*illuminating idea*" regarding activated sludge, referring to Lawrence as the *"Mecca of sewage purification*."

Although disappointed with his prior aeration experiments, Fowler quickly seized upon the concept of employing a suspended biomass culture and initiated several related experiments upon returning to Manchester, England. One year after the Lawrence tour, Fowler and one of his graduate students, Mrs. Mumford, published their successful results covering a suspended-culture aeration system inoculated with iron salts and an special ' M-7' iron bacterium. (Fowler & Mumford, 1913) Their treatment scheme sequentially employed a ‘ blowing tank’ and clarifier. However, their system had two shortcomings. First, since it did not have a means of recycling solids, the unit required continuous inoculation with their mysterious M-7 organisms. Secondly, Fowler at this point was laboring under the misconception that his special ‘ iron’ bacteria played a major role in the overall efficacy of the process. To some extent, this misunderstanding might have been linked to the use of coagulating, iron-rich blood started fifty years earlier with the ABC Process. This misunderstanding about the role of iron and iron-bacteria, though, would then persist for more than a decade (Wolman, 1927).

At this point, 31 years had elapsed since Dr. Smith first examined the aeration of sewage. However, the seemingly simplistic notion of accumulating a suspended biomass through solids recycle was still unknown. Hence, the revelation by Fowler’ s students, Ardern and Lockett, in May 1914 that these humus solids should be saved rather than discarded proved to be an unqualified "*bombshell*" (using Fowler’ s description, provided during an audience reply following presentation of Ardern and Lockett’ s paper).

Ever sensitive to the fiscal realities of academic research, Ardern and Lockett acknowledged their gracious appreciation for the monetary support which had been provided by the ‘ Worshipful Company of Grocers.’ (Ardern & Lockett, 1914b) In retrospect, the fact that ‘ grocers’ would have been interested in this sort of research topic does seem rather odd. However, upon reading the audience comments following their presentation, it is readily evident that they genuinely thought this system’ s waste sludge would yield a marketable product given its nutrient content. Here again, as with the prior ‘ ABC’ process, they were optimistically interested in recovering nitrogen and phosphorus which otherwise was in critically short supply as a raw fertilizer feedstock. Rather ironically, though, their ever-present shortage of fixed nitrogen would shortly have an even more dramatic impact relative to its necessity for manufacturing the munitions which would be needed for World War 1. Germany’ s acute awareness of this problem led them (i.e., via Fritz Haber’ s Nobel-winning research) to develop industrial processes for synthesizing ammonia and nitrates…at which point the opportunity or need for recovering nitrogen from sewage largely became a moot issue.

Using fill-and-draw cycling, these latter authors had provided the premier demonstration and pronouncement of activated sludge treatment. Even with viewed in the context of our contemporary operations, their initial experiments were remarkably advanced. Indeed, their presentation addressed such topics such as energy conservation, sludge handling, and the sensitivity of nitrifying organisms to temperature and pH, all of which are still debated in our contemporary literature. Perhaps more importantly, the audience of Ardern and Lockett’ s presentation immediately recognized the monumental value of their discovery.

LAB TO FIELD TRANSOFRMATION OF THE ACTIVATED SLUDGE PROCESS:

1914 -> 1920’ s

Ardern and Lockett subsequently presented two further papers in 1914 (b) and 1915 which touched on a range of practical issues, including: performance capabilities during continuous-flow and fill-and-draw operation, the detrimental impact of trade wastes, aeration levels using plain tubes and porous tiles, required aeration intensities, and biomass acclimation. The startling fact that it could reliably produce clear, non-odorous effluents had extreme appeal for municipalities long frustrated with their aesthetically unattractive options. Even as Fowler’ s pioneering research continued, therefore, the process was already being tested on full-scale basis. In fact, at the same 1914 meeting that Ardern and Lockett presented their second paper, Melling (1914) announced that he had successfully applied activated sludge treatment to an 80,000 gallon per day flow at Salford, England.

In quick succession, several full-scale English installations were placed into operation. The following listing provides a chronological summary of these facilities: Salford, 1914, Davyhulme, 1915; Worcester, 1916; Sheffield, 1916; 1917; Stamford, 1917; Tunstall, 1920; Sheffield, 1920; Davyhulme, 1921; and Bury, 1921. In the United States, progression of the activated sludge process moved with similarly amazing speed. Edward Bartow, a Professor at the University of Illinois, visited Fowler' s group in Manchester in August of 1914 and subsequently began his own bench-and pilot-scale experiments along the lines established by Fowler' s group. Within a period of several months, numerous other American researchers initiated similar studies, including those by Hammond, Hendrick, Hurd, Frank, Mohlman, Hatton, and Pearse. (Maring, 1927; Pearse, 1938; Metcalf & Eddy, 1916;

Babbitt, 1926) Full-scale U.S. installations began to appear to 1916, and by 1927 there were nearly ten full-scale systems spread throughout the country, including: San Marcos (TX), 1916; Milwaukee (WI), 1916; Cleveland (OH), 1916; Houston (TX), 1917 & 1918 (2 each); Des Plaines (IL), 1922; Calumet (IN), 1922; Milwaukee (WI), 1925; and Indianapolis (IN), 1927.

ENTREPRENEURIAL TRANSFORMATION OF ACTIVATED SLUDGE:

1913 -> 1940' s

Within less than a decade, this rudimental, bench-scale concept had been installed at numerous multi-MGD facilities. Based on its rapid growth during these first few years, it would seem that activated sludge would have become the preeminent wastewater treatment process virtually overnight. However, despite this initial intensity, activated sludge did not truly find widespread application for several decades.

The cause for this delay is quite simple; namely, patent litigation curtailed most of the technical momentum. Whereas Ardern and Lockett presented their research findings in May of 1914, another pair of wastewater entrepreneurs (i.e., Jones and Attwood, Ltd.) had actually beaten them to the punch by nearly a full year, filing four separate patent applications dealing with "Improvements in Apparatus for the Purification of Sewage or other Impure Waters" (UK patents #19915 at 1913; #22952 at 1913; #729 at 1914; and #19916 at 1914). (Jones & Attwood, 1913ab; 1914; 1915) Of these four, none actually employed the term ‘ activated sludge’ . No. 729 clearly included the basics of the process though, particularly because of its specific reference to solid recycle. Furthermore, the reactor figures provided by this latter patent bear a striking similarity to contemporary looped designs marketed by several proprietors.

Jones and Attwood must also be credited with much of the preliminary work towards establishing the practical application of activated sludge. Several of the original full-scale facilities (e.g. Worcester and Stamford) were, in fact, solely constructed at their expense and risk as a means to demonstrate its pragmatic merit. In fact, the Worcester system was designed and installed under a performance-based contract based on effluent quality.

The patent situation for activated sludge became even more complex in 1915 when Leslie Frank, a U.S. Public Health Officer, obtained an American Patent (#1,139,024) which covered much the same material as the Jones and Attwood claims. (Frank, 1915) Frank, however, dedicated his patent for "activated sludge" (the misspelling reflects Frank’ s terminology) to all U.S. citizens.

Hence, at this point, there were two different patent entities dealing with activated sludge. Aside from these legal claims, Flowler's own standing as the originator of activated sludge was also being disputed by Clark at Lawrence. (Clark, 1915; Mohlman 1938; Greeley, 1945) However, despite this confusion regarding the legal status and origination of activated sludge, the American engineering community pushed ahead with its technical application.

In late 1914, Jones and Attwood, Ltd. Warned American engineers and cities that they should use caution regarding patent infringements. (Hatton, 1916) And when American engineers took credit for certain innovations which transgressed into their (i.e. Jones and Attwood, Ltd) patented procedures (e.g., Clarence Hurd's announcement of the spiral-flow aeration pattern being used at Indianapolis), they were quickly rebuffed by the Jones and Attwood group. (Hurd, 1929; Sandford, 1929) But as more and more plants were built, municipal concerns about patent problems and complications diminished.

This mood quickly changed, though, with a suit filed by Activated Sludge, Ltd. (the licensed patentee for Jones and Attwood, Ltd.) against Chicago in the late 1920's. (Anonymous, 1933) Additional suits against Milwaukee, Cleveland, Indianapolis, and several smaller cities soon followed. Legal rulings on all of these cases took several years, during which time the sanitary engineering profession seriously reassessed the prospects for near-term activated sludge utilization. In 1933, District Judge Geiger ruled that Milwaukee had, indeed, violated patents held by Activated Sludge, Ltd. (Anonymous, 1934a,b) An appeal was submitted, but in October, 1934 the Supreme Court declined to rule against this decision.

In reflecting upon this outcome, Bloodgood (1982) indicated a belief that the District Judge ruled against Milwukee moreso because of their outspoken lawyer than the involved legal details. Whatever the case, the infringement ruling immediately rippled throughout the country. Several existing plants quickly shut down to avoid monetary fines, including the original San Marcos, Texas facility. (Otts, 1982) Many others chose to continue their use of the activated sludge process based on a royalty fee of 25 cents per capita. Amongst the 203 plants, Kappe (1938) reported that 150 were licensed by Activated Sludge, Ltd. (Kappe, 1938) As for the large number of communities planning to install new activated sludge plants, most simply elected either to build an alternative system (oftentimes a trickling filter) or to wait until the applicable patents expired (e.g. Washington, D.C. was a prime example).

Milwaukee and Chicago appear to have suffered the largest losses with each being fined just under one million dollars (Activated Sludge, Inc., 1946) In Milwaukee's case, these monies were secured from the proceeds on a relatively new (i.e. since 1926) sludge product, Milorganite, whose annual sales in 1934 were estimated at 3 million dollars. In retrospect, Chicago probably wishes it had accepted the terms of an out-of-court settlement offered by Activated Sludge, Ltd. (Activated Sludge, Inc., 1946) Rather than paying for the imposed fine and several years of legal involvement, the case could have been settled with a $90,000 settlement.

ACTIVATED SLUDGE SUPREMACY:

1950's -> present

Once the business of building wastewater treatment plants hit its peak in the United States following World War II, the activated sludge process quickly became the dominant design approach for secondary systems…and this 'supremacy' remains in effect to this day. Had it not been for the litigation stemming from its original British patents, this transition from fixed film processes would probably have moved even faster. At this point in time, though, activated sludge has proven itself to be durable technology in an era where most engineering methods lapse into obsolescence only decades, if not years, after their original development.

SUMMARY

Sixteen years ago Frank Schaumburg published this ’ Figure’ as a stand-alone paper with the *Journal of the Water Pollution Control Federation* (**NOTE:** Even today, it is still considered to be one of the most succinct publications ever carried on the topic of activated sludge!). Entitled, "65 Years of Efficiency Progress in Activated Sludge," the late Professor Schaumburg’s goal was to visually (and probably sarcastically) demonstrate - the fact that the performance levels achieved with activated sludge (i.e., BOD removal efficiencies) have changed extremely little over the decades in spite of considerable research and publication on the topic! It worked well when first developed, it works about the same today, and it should serve our needs for many more years. Ironically, though, the problem of handling the resultant sludge, which Melling cited as their "*greatest bugabear*" while commenting on the landmark paper in 1914, still remains a distinct challenge!

ACKNOWLEDGMENTS

The figures included within this text were respectively scanned from the following sources:

-Pg. 1, *Punch*, pg. 41,31 July 1858;

-Pg. 2, top, Reyburn, W. (1989). "*Flushed with Pride*," Pavilion Books Limited, London, UK;

-Pg. 2, bottom, *Punch*, pg. 71, 14 August 1858;

-Pg. 3, Minutes of Evidence, Royal Commission on Metropolitan Sewage Discharge, Vol. III,

From May 1884 to October 1884 (1885);

-Pg. 4, Ardern, E. and Lockett, W.T. (1914). "Experiments on the Oxidation of Sewage Without the

Aid of Filters." *Journal of the Society of Chemical Industry*, *33*, pg. 524, 30 May;

-Pg. 7, Schaumburg, F. and Marsh, B.E. (1980), "65 Years of Efficiency Progress in Activated

Sludge," *Journal of the Water Pollution Control Federation*, 51, pg.1.