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Notes on process and data analysis in electro-coagulation—The importance of standardisation and clarity

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ABSTRACT

Electro-coagulation (EC) is an alternative method to standard chemical coagulation, which is one of the most common water and wastewater treatment processes, employed to remove a wide range of contaminants through (co)precipitation processes. Despite the attention EC has received over the last decade, misconception regarding key process parameters exists and a lack of standardised procedure impacts on the progress of this promising field.

It is demonstrated here how, unlike frequently reported in the literature, a fundamental process parameter – current intensity – is the process determining step with regards to extent of contaminant removal (rather than current density). Furthermore, terminology is proposed with a view to unify communication and to facilitate performance interpretation and comparison of datasets whilst the jar-testing procedure is presented as standardized method for process evaluation with the same objective in mind. Finally, shortfalls and solutions to experimental design are discussed and presented.

1. Introduction

1.1. Objectives

Given the significant pressure put on existing water resources by population growth and industrialisation, the requirement for effective and efficient water treatment technologies is pressing. Due to its versatility and broad scope, coagulation is one of the most common water and wastewater treatment processes, ubiquitous to both industry and municipal treatment plants. Consequently, it is not surprising that as a technology that offers the possibility of carrying out effective water treatment in a compact footprint and with low chemical consumption, electro-coagulation (EC) has received significant interest over the past decade. The large number of publications is a testament to this, with recent extensive reviews covering a broad range of topics, from fundamental research [1,2], application specific testing [3,4] or design engineering [2]. A common conclusion stands out: EC has potential as a viable water treatment technology.

Against this promising background it is surprising that the technology has not become mainstream given that the first reported installation in London dates back to 1889 [4] and a US patent for purification of wastewater by electrochemical corrosion of iron and aluminium electrodes was submitted as early as 1909 [5].

The barrier for technology uptake seems to result from the inexistence of standardised process and hardware development evolving into a well characterised product which industry can confidently operate. Although the process principles have been studied for decades, the 'chemical journey' of a metal particle from the electrode surface until it reaches bulk solution is still not fully understood [2,6–8]. The majority of the research effort has been centred on enabling treatment of a particular contaminant, leading to application-specific knowledge rather than a mechanistic understanding. The reason behind this outcome seems to be the difficulty in evaluating process parameters in isolation due to the multitude of phenomena occurring simultaneously at the electrode surface and bulk solution. Holt et al. [9] summarised in a clear and conceptual way how the field of electro-coagulation results from the overlap of three independent subjects that 'come together' when EC is implemented: Electrochemistry, flotation, coagulation (Fig. 1).

The complexity of the subject renders a mechanistic approach harder to implement and therefore carrying out contaminant-centred studies has been a generally preferred, albeit more limited, approach. Perhaps as a consequence of this multitude of 'individual case studies' that comprises a large section of EC literature, there is

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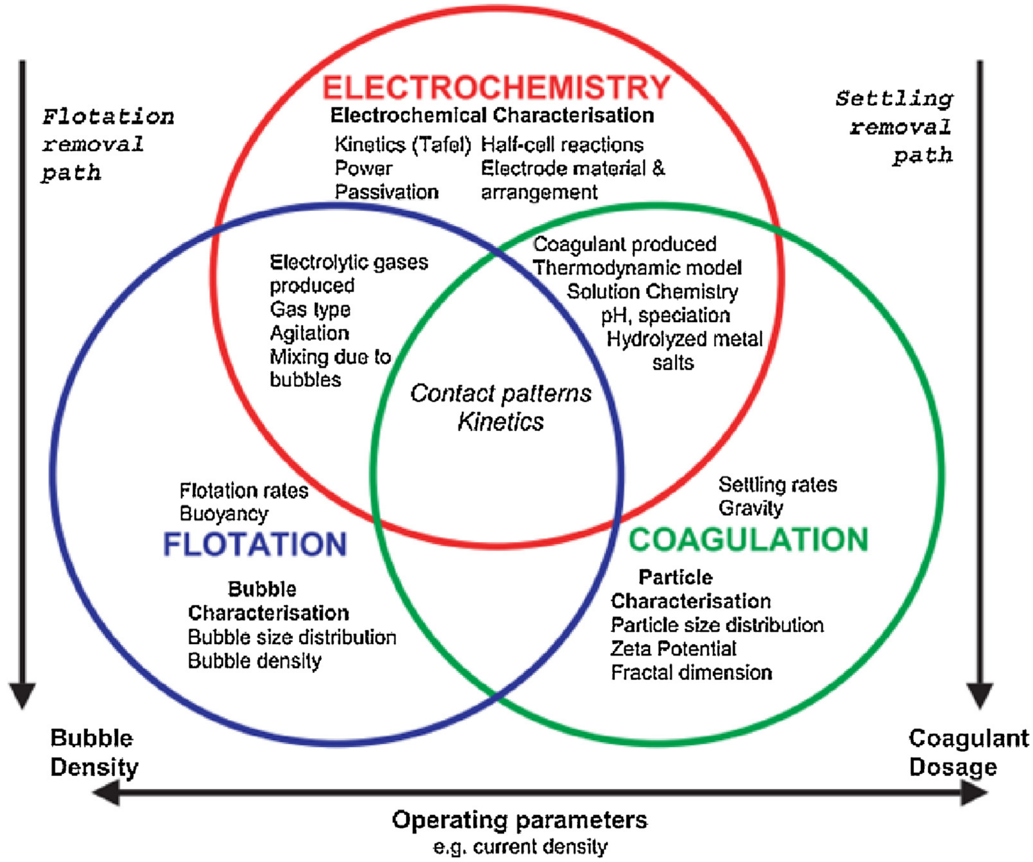

Fig. 1. Conceptual framework for electro-coagulation as a 'Synthesis' technology [9].

great variability in the way results are generated, interpreted and reported that compromises the ability to efficiently progress the know-how and credibly take this technique from a research topic to a well-established, mainstream, technology.

The main purpose of this work was to bring clarity to the way key data is generated and reported within EC research and pointing out the benefits of standardisation in the reporting of data and experimental process, in particular process performance evaluation.

To support these arguments, a study was carried out to demonstrate a fundamental aspect of the process: which parameter limits process efficacy (current density or current intensity). The study was carried out over a range of model contaminants (heavy metal—Zn, nutrient—P and suspended solids—kaolin) to demonstrate that results are not contaminant specific but rather a general process trend.

Post EC treatment, model 'effluent' samples were processed using an industry standard procedure – jar-testing – with a view of introducing repeatable and reproducible methodology that also finds comparability with industrial processes. The aim is not only to standardise evaluation of process performance across research, but to do so in a way industry can readily evaluate and translate to plant performance, thus enabling quicker uptake of the research developments.

In brief, specific objectives are:

- Demonstrate that current intensity (i.e. dosing concentration) is the key performance-limiting parameter in EC (i.e. determinant for removal efficacy)
- Demonstrate that current density plays a secondary role in removal efficacy
- Standardise process performance evaluation and present terminology

1.2. Coagulation background

A wide range of contaminants can be removed from various effluent streams through a procedure of (co)precipitation where metal hydroxides (of Al of Fe) are formed within the effluent stream to 'capture' contaminants. The process is commonly known as coagulation and is carried out through the addition of a precipitating agent (most commonly Al^{3+} or Fe^{3+}) to the effluent stream which, at suitable conditions (e.g. pH), forms insoluble aggregates that bind to the contaminants and form a sludge that can be physically separated from the aqueous phase (e.g. by settlement, flotation, filtration). This process is widely used in municipal wastewater treatment plants to remove solids and nutrients from effluent streams and by a broad range of industries to remove specific contaminants from process streams (e.g. heavy metals, dyes, bacteria, phosphorous . . .).

Whilst chemical coagulation is the standard procedure in industry, where soluble salts of Al or Fe are used (e.g. $Al_2(SO_4)_3$ and $FeCl_3$), this can be replaced by an electrochemical alternative (EC) where the precipitating agent (e.g. Al^{3+}, Fe^{3+}) is generated by corrosion of metallic electrodes of aluminium or steel. The use of electrodes as the vehicle for delivery of Fe or Al ions to solution, effectively replaces chemical dosing stations with more compact electrochemical reactors [6], since the metallic phase is a far more compact way of transporting Fe or Al compared to aqueous salt solutions.