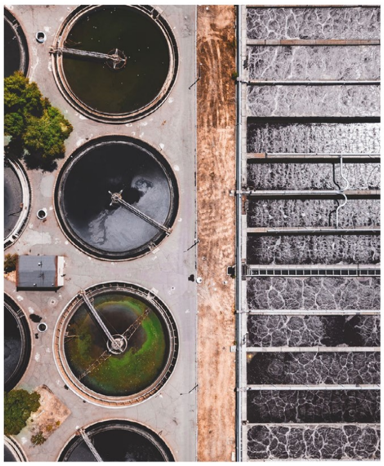
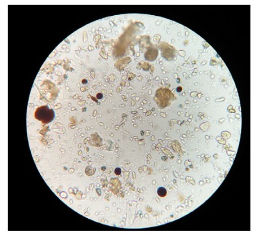
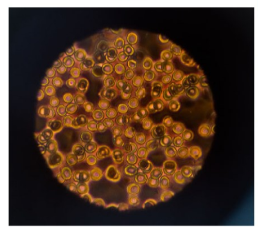
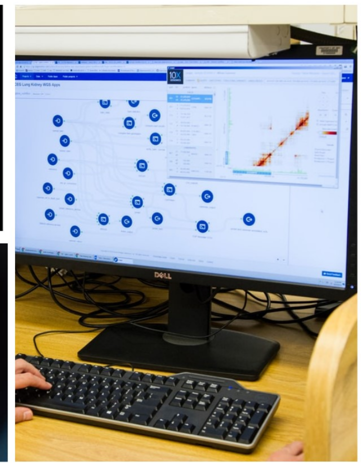
Automating Bioreactor Performance Recommendations from Sludge Microscopy Images



BACKGROUND

Aerobic and anaerobic biological treatment processes are integral to municipal and industrial wastewater treatment. The core engines of these processes are the microorganisms that biodegrade the organic carbon, nitrogen, and phosphorous in the wastewater.

Municipal and industrial wastewater treatment plants constantly strive to strike a delicate balance between regulatory and economic drivers to be more efficient in terms of energy consumption, waste generation, OpEx, and human resource intensity for plant management and operations. Municipal plants frequently cope with variable influent quantities, impacts of rainfall and storms, as well as on-site sludge handling issues. Industrial plants can have the added challenge of high variability in composition of the influent wastewater, which can make frequent excursions from the design values, yet requiring to maintain their effluents below strict regulatory limits. Maintaining this delicate balance between productivity, regulatory compliance, and economy by continuously maximizing the efficiency of the reactions performed by the microbiome present within the biological treatment system is a challenging task. Failure to maintain the reactions optimal could lead to consent limits being threatened due to solids carryover or incomplete treatment.

Microscopic examination of activated sludge or fixed film biomass has often been recommended, and sometimes used to identify the causes of poor effluent quality, poor sludge settling, foaming, odors, imperfect solid compaction, and other operational problems in bioreactors. Microscopic examination of the mixed liquor or biofilms can be used to identify the biotic causes of many operational issues in bioreactors. Once the microbiological reason has been established, actions can be taken to eliminate the underlying causes. These could be simple things like

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introducing or increasing assimilable COD (food), enhancing or reducing aeration intensity, and adjusting recycle of solids.

In many cases, microscopy of the sludge is recommended as a troubleshooting tool to obtain corroboration of performance issues (such as sludge settleability impairment) after a problem is encountered at a biological treatment plant. However, a microscopy analysis embedded in the routine plant performance monitoring regime combined with an automated, self-learning, and continuously improving image analysis tool to provide process guidance can be beneficial to biological treatment plants. Such an approach, along with other process variables, can proactively ensure process stabilization and optimal performance of the bioreactor.

METHODOLOGY

Sample Collection and Microscopy

Samples of biomass are collected from the biological reactors at the wastewater treatment plant. This may be the mixed liquor in the reactor or samples of fixed films scraped from MBBR substrates, MBR membrane surfaces, or trickle bed media. The samples should be examined as soon as possible after collection – often with minimal preparation. Key observations should be made of the floc structure, protozoa and metazoa populations, filamentous bacteria (type and abundance/length), and the clarity of the bulk liquid (space between the flocs).

The frequency of analysis should be tailored to the site. For the most part, weekly or monthly samples are sufficient for a regular check on the health of the plant. If the analysis is being used to monitor process changes or the commissioning of new equipment, then this frequency might be increased to daily or a few times a week for the duration of such changes at the plant.

The microcosm sample collection and microscope slide preparation are often standardized at each treatment facility, including collection volumes, locations, time, delay in slide preparation, and slide staining.

The microscopy methodology and procedural settings, such as brightfield or phase contrast, magnification, settings of the digital camera, acquisition of video, or single images, are also defined by the laboratory microscopy technician and are used consistently to acquire the image data.

Significant variability exists in the samples collected, sample collection procedure, as well as the microscopy procedure from plant to plant. For this reason, we recommend that images acquired at individual plants or microscopy laboratories be used as separate databases to ensure consistency in the standard operating procedures to acquire the images.

An optical microscope is generally available in laboratories of water treatment facilities. Acquiring digital images from the microscope is straightforward. IntelliFlux helps set up the microscopy and automated image acquisition system.

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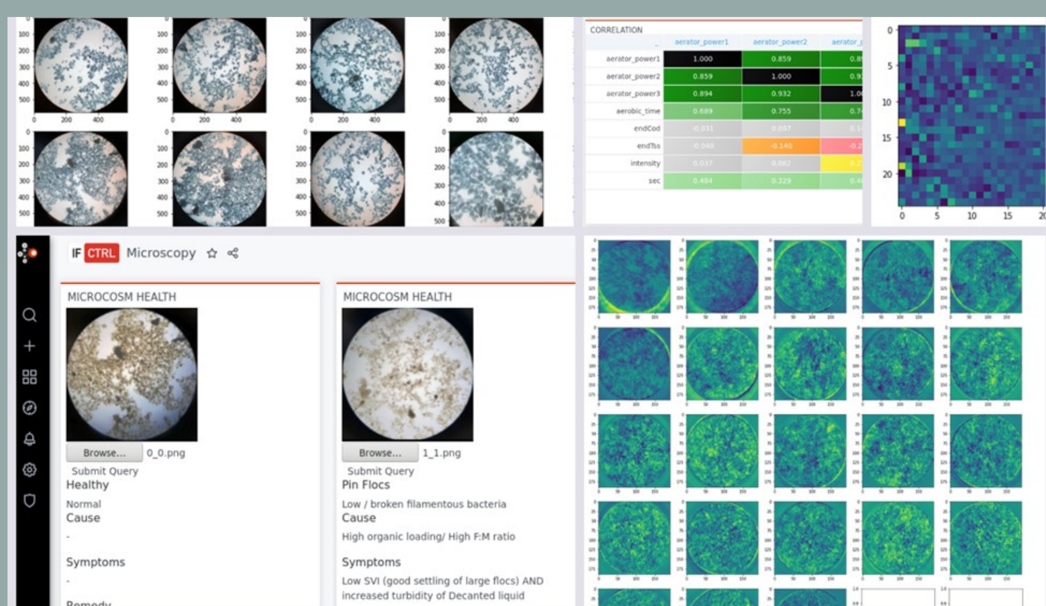
Learning and Predicting Bioreactor Performance

IntelliFlux provides a toolkit to standardize the microscopic image collection, cataloging and time stamping, and uploading them to an image database for the water treatment plant.

The images in the database are pre-processed and standardized for use in training a neural network algorithm. A convolution neural network (CNN) is trained using the image data, following which different classification algorithms are used to test the viability of the trained model to identify images representing normal healthy state of the microcosm, and various anomalous states, such as filamentous bulking, zoogleal bulking, pin floc formation, etc. With respect to each anomalous state, the symptom observed in the microscopy slide, the prevalent Food to Microorganism Level in the reactor, the dissolved oxygen (DO) level for aerobic systems, sludge age, and other reaction conditions are correlated. For each anomalous state of the microcosm, correlations between the potential cause and prescribed remedies are also embedded in the classification process.

The microscopy technician in the laboratory can provide descriptors for the images when they upload a new image. For instance, the operator could indicate an image to be representative of pin flocs or note the absence of any protozoa. The information provided by the technician helps label the images as they are uploaded to the database. The learning algorithms use images as they are included in the database to improve the accuracy of the predictions over time. Within three months (collecting one primary image daily giving a total of 90 primary im-

IntelliFlux SmartSCADA embeds learning algorithms to recognize features in the microscopy images, link these to the microbial population health, and relate these to the reactor operating conditions. The microscopy technician uploads the image, and either characterizes features in the image (reinforcement learning and labeling), or sends a query to the software to obtain process guidance.



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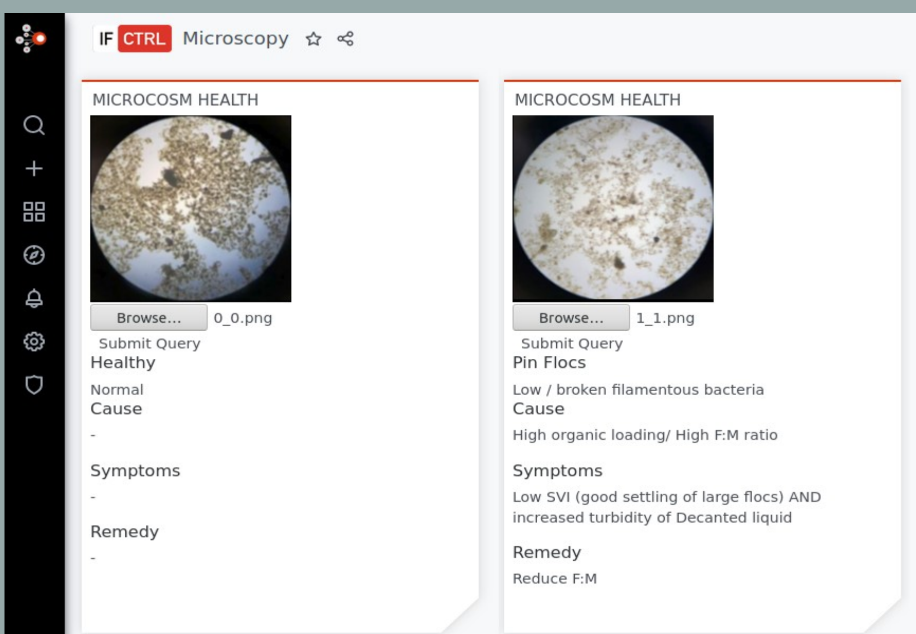
ages), the AI develops sufficient accuracy to identify normal and abnormal states of the microcosm with a > 90% accuracy. With improved ability to correctly classify the images, and correlate these with reaction conditions and reactor performance, the software can recognize features representing potential anomalies and suggest remedies to the operations team at the plant.

The microscopic observations are used in conjunction with other measured performance variables for the plant, as well as local operating conditions of the plant, thereby creating a progressively rich database of how the microbial activity depends on the temperature, seasonal condition changes, changes in influent quality, as well as operating conditions.

PROCESS RECOMMENDATION

Predicting Reactor Condition from Microbial Population Health

Performing microscopy on sludge samples dramatically improves the ability of the plant operations personnel to proactively address and mitigate potential problems that can normally take a long time to be corrected. Observing proliferation of filamentous bacteria in microscopic images, and being able to correlate this with higher sludge volume index or poor sludge settleability provides operators tremendous confidence in mitigating these issues in a timely manner. High levels of filamentous bacteria can lead to



IntelliFlux SmartSCADA responds to queries with process symptoms and recommendations that are clearly interpreted and understood by plant operators. The operator can interact with the tool without having to be a microscopy or image processing expert. Here, a microscopy image uploaded to the widget shows a probability of pin-floc formation, and suggests potential remedies.

poor settlement, and at its worst, a highly viscous mixed liquor. This, in turn, affects efficient oxygen transfer, further exacerbating the low oxygen conditions. Return liquors from sludge handling can be a rich source of the septicity that this filamentous species can thrive under. If there is insufficient aeration capacity to drive off the septicity, the activated sludge can rapidly deteriorate. Improving aeration, or even using sodium hypochlorite to reduce the length of the filaments can be the recommended steps.

Using a self-learning computer program to perform feature recognition in these images provides algorithmic precision in selectivity, continuity, and sensitivity in the pattern analysis and recognition. These results are often more consistent than getting subjective evaluation of microscopy images based on visual observation from different observers, technicians, or consultants. If such a process is embedded in the automation framework of the plant, then process control variables, such as throughput, dissolved oxygen (DO) levels, recycle activated sludge, and sludge wastage rate can be adjusted using recommendations from such microscopic image analysis. It is even possible to correlate the microscopy images with the readings of an Oxidation-Reduction-Potential (ORP) sensor.

The microscopy and AI based process recommendation described here can immensely help the treatment plant operations teams to ensure stable operation at the plant. Embedded into a daily or weekly laboratory analysis schedule, the cost of implementing such image acquisition protocols is a fraction of the cost of performing a BOD and COD fractionation analysis at an off-site laboratory. However, embedding an image classification based automated and objective recommendation system for the bioreactor can even help operators with minimal microscopy and image analysis experience to ensure optimal process stability.

APPLICATION SUMMARY

APPLICATION AREA: **MUNICIPAL WASTEWATER TREATMENT**

CUSTOMER: **MUNICIPAL REUSE OPERATOR**

LOCATION: **MIDDLE EAST**

SYSTEM: **SEQUENCING BATCH REACTORS**

CAPACITY: **36000 cubic m/day**

OPERATED: **2020**

BENEFITS: **PROCESS OPTIMIZATION**

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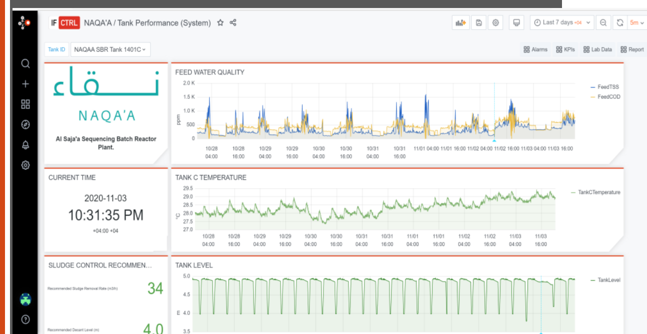
CONCLUDING REMARKS

Digital transformation provides water treatment plants unique opportunities for integrating laboratory analysis, water quality, and process monitoring data into operations decision-making and process control. The present case study shows how IntelliFlux SmartSCADA platform can be configured readily to provide a tool for uploading microscopy images, catalog these, perform image processing and classification, and utilize machine learning to provide process guidance. The toolkit was developed using the IntelliFlux software at a biological wastewater treatment plant.

With this tool in place, the operations and engineering team can collect a sludge sample at any time and upload the microscopy image to the software. The software immediately provides an assessment of the image, indicating the condition of the microcosm in the reactor, and recommendations for process management. Images from different dates can be compared using the tool to assess trends in the reactor operation.

The tool is also being used as a reinforcement learning platform by the operations team at the plant where they are guiding the AI algorithms regarding the correlations between the microscopic images and other process conditions.

THE INTELLIFLUX TECHNOLOGY



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