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MINIMIZATION OF ODORS AND CORROSION IN COLLECTION SYSTEMS

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ABSTRACT AND BENEFITS

Abstract:

Wastewater collection system odors and corrosion issues continue to grow in importance to the community and to system owners and operators. Odor and corrosion prevention in collection systems has historically been as much art as science. Common control methods are selected based on practical experience as opposed to a fundamental understanding of why and when methods will be successful. Although much is known regarding the cause of odorous gases in the collection system, the underlying science and mechanisms of odor generation, sewer ventilation, odor characterization and monitoring, and corrosion mechanisms need further research. This WERF research activity helps odor-control specialists transition from “odor artists” to scientists and engineers, while also providing a useful tool both for designers to successfully prevent odor and corrosion events through proper design and for operators to mitigate and prevent odor excursions and corrosion impacts.

This project transfers state-of-the-art technology and information gained from the literature survey to the collection system owner and designer on odor and corrosion assessment, measurement, characterization, monitoring, and prevention. The field studies identified in this Phase 1 effort will fill high-ranked knowledge needs. The resultant database and team-developed, web-based application tool will identify the best practices for the entire collection system and its associated facilities, infrastructure, equipment, and pipes.

In addition, because odor problems are often measured subjectively by the number of public complaints, the final database and application tool will provide insights on how and why peer utilities responded and how effective their response was in solving the problem. Application tools geared for best practices related to odor and corrosion measurement, monitoring, and prevention save utility funds, allow easier asset management, and, in many cases, prevent significant environmental damage and human health impacts due to corrosion-related sewer overflows. Our proposed web-based application tool will be formed by practicing experts and utilities, “ground-truthed” by peers and others, and tested by our utility members before being offered to WERF members. This approach ensures an application tool that can be readily updated, is always current, and practically addresses any odor or corrosion-related issue.

Our efforts to compile a current knowledge database includes information-sharing partnerships with municipal utilities, the academic community, and the profession, all on a global basis. Our team includes leading odor and corrosion control researchers in the academic, utility management, and consulting communities, and part of their role will be to provide exhaustive literature research efforts through catalogue reference, gray literature review, and Internet search mechanisms. WERF member utilities have participated in the database compilation efforts both by helping to define the database information needs, and by helping to access utility information from WERF member and nonmember utilities.

A five-step approach is being used:

1. Assemble a database of prior research, literature, and gray utility studies
2. Evaluate the database for quality, accuracy, and completeness, and conduct supplemental information gathering and/or do field testing to fill highly ranked knowledge need areas

3. Classify items in the database for easy searching and use by collection system owners and designers
4. Add information to the database from field studies, further literature searches, and other "independent" research efforts by our utility partners
5. Develop a collection system evaluation software application "tool" for agencies

Our team provides a global perspective on collection system odors and corrosion needs and monitoring that has proved successful in several countries (Australia, Singapore, New Zealand, England, and North America) and applied worldwide. Our team members are all practicing collection system experts, from major research institutions, highly specialized and qualified consultant firms, and numerous agencies. This combination of talent was brought together to bring WERF subscribers an excellent source of industry knowledge and a comprehensive database and application tool.

A plain-English guide providing a useful and easily understandable overview about odor and corrosion in collection systems including how odor and corrosion compounds are formed and what to do to control them is provided as an introduction to this document.

This Phase 1 report then summarizes the state of the art in knowledge related to odor and corrosion in collection systems. This highlights the latest knowledge reported in the literature.

Our efforts to compile the literature database have included information-sharing partnerships with municipal utilities, the academic community, and the profession, all on a global basis. Our team included leading odor and corrosion control researchers in the academic, utility management, and consulting communities, and part of their role was to provide exhaustive literature research efforts through catalogue reference, gray literature review, and Internet search mechanisms. In this way we have accessed a broad spectrum of global resources tapping into the knowledge and experience of both WERF member and nonmember utilities.

Benefits:

To date, the focus on odor and corrosion prevention has been on a case-by-case basis, experimenting with what works and applying knowledge based on several known generation mechanism and either liquid phase or gas phase prevention approaches. This research reflects a more holistic approach, with experts representing diverse perspectives: utility and asset management, affordability, regulatory and permitting, public outreach, characterization, assessment and measurement, and system planning, design, odor and corrosion abatement, and operation and maintenance.

Keywords: Collection system, odors, corrosion, hydrogen sulfide

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BOD	biochemical oxygen demand
CFD	computational fluid dynamics
cfm	cubic feet per minute
CIPP	cured-in-place pipe
COD	chemical oxygen demand
D/T	dilutions-to-threshold
DO	dissolved oxygen
EBRT	empty-bed residence time
ECIS	east central interceptor sewer
EPA	U.S. Environmental Protection Agency
FOG	fats, oils, and grease
FSC	flameless sulfur chemiluminescence
GC/FID	gas chromatography with flame ionization detection
GC/FPD	gas chromatography with flame photometric detection
GC/MS	gas chromatography with mass spectrometry
GC/MS/O	gas chromatograph mass spectrometer olfactometer
GC/NPD	gas chromatography with nitrogen-phosphorus detection
HS-SPME	headspace solid phase microextraction
LACSD	Los Angeles County (Calif.) Sanitation District
LCA	life-cycle analysis
LEL	low explosive limit
MBR	membrane bioreactor
MIC	microbially induced corrosion
OCSD	Orange County (Calif.) Sanitation District
OEC	odor emission capacity
OP	odor potential
ORP	oxidation-reduction potential
OU	odor unit
PDMS	polydimethylsiloxane
POTWs	publicly owned treatment works
ppb	parts per billion
ppm	parts per million
PSA	pressure swing adsorption
QA/QC	quality assurance/quality control
SPACA	septicity prediction and control algorithms
SPME	solid phase microextraction
SRB	sulfate-reducing bacteria
TON	threshold odor number
VFA	volatile fatty acid
VOC	volatile organic compound
WATS	wastewater aerobic–anaerobic transformations in sewers
WERF	Water Environment Research Foundation

EXECUTIVE SUMMARY

Odor complaints, corrosion, and costly sewer rehabilitation projects are damaging public relations, degrading wastewater facilities, and stressing already-limited collection system budgets. Research has revealed several seemingly unrelated factors that in combination cause the increased collection system odor and corrosion problems that municipalities face today. Significant gaps exist in our understanding of odor production and corrosion in collection systems. As a result, odor and corrosion prevention in collection systems is as much art as science.

In response to these issues, the Water Environment Research Foundation (WERF) selected King County (Wash.) Department of Natural Resources and Parks—Wastewater Treatment Division and CH2M HILL to conduct a 2-year project focusing on minimizing and preventing odors from, and corrosion of, wastewater collection systems. Our team includes practicing wastewater collections systems experts from major university research institutions, highly specialized and qualified consulting firms, and numerous collection system owners and operators. The 2-year project is divided into three phases: 1, literature assessment; 2, research agenda implementation; and 3, practitioner's guide.

This Phase 1 report presents the results of a comprehensive literature review and assessment. It focuses on the odor and corrosion approaches, strategies, challenges, and successes and failures as described in both the open peer-reviewed and gray literature. Our efforts to compile the database included information-sharing partnerships with municipal utilities, the academic community, and the profession, all on a global basis. Current literature on wastewater collection system odor and corrosion was identified and reviewed systematically, and each paper's essential information was documented electronically.

The published literature search generated 2,945 references, of which 263 were deemed worthy of inclusion in the database. These papers were mostly conference papers and journal articles published after 2000. The gray literature search generated 52 papers from nine organizations. Of these, 33 contained information relevant to the project and were included in the database. From a previous WERF study 317 papers were screened (published and gray) and 85 were included in the review. The quality control process generated an additional 44 papers identified by the project team. A Googlescholar search produced 485 references, 14 of which were worthy of inclusion in the database, but had not yet been identified. The total number of references screened was 3,842, with a total of 435 papers included in the database. Nineteen of these papers were printed in a foreign language and were not translated, and four could not be obtained. The total number of papers included in the database was 412.

A "plain-English" guide gives a useful and easily understandable overview of odor- and corrosion-causing compounds in collection systems, including how these compounds form, how they are measured, and how they can be controlled. As well as being a comprehensive overview for the layperson, the plain English guide introduces the pertinent topics for the wastewater professional and the literature search findings discussed in more detail in the chapters that follow.

First, in Chapter 4 our team describes advances in identifying malodorous compounds emitted from sewers, biological mechanisms through which odorous and corrosive chemicals form in sewers, and emerging measurement methods. Insights into state-of-the-art methods for measuring and preventing the formation of odor- and corrosion-causing compounds are presented. For example, we observed that past studies related to corrosion in sewers have focused almost entirely on the production and release of hydrogen sulfide and formation of sulfuric acid that leads to corrosion of sewer pipes. Additional research related to whether other biochemical reaction products in sewers lead to corrosion, or enhance the corrosion related to hydrogen sulfide releases, is warranted. It was concluded that fermentation processes and volatile fatty acid formation remain areas of uncertainty and are worthy of additional basic (laboratory) research. Furthermore, the concept of odor potential should be expanded to include not only the current state of wastewater but also the potential to form odorants following chemical and biological transformations. This necessarily requires greater knowledge of parameters that lead to transformations and the transformation pathways themselves, and thus a need for more laboratory research. Additional field studies are needed to link sensory perceptions of odor complaints, that is, annoyance, with the chemical composition of odorants. Olfactory gas chromatography with mass spectrometry enables odorants in gas samples to be separated and identified individually and allows for the odor contribution of each compound to be characterized and quantified using an odor port. Finally, two promising technologies that might facilitate the identification of odorous gases and/or nature of odors include solid phase micro-extraction for the concentration of trace concentrations of odorous compounds and electronic nose systems. However, each of these technologies requires further laboratory research, and ultimately field evaluations, to optimize

Next, in Chapter 5 we explain recent advances in modeling wastewater collection system odors and corrosion. Six models are reviewed and evaluated, and their strengths and weaknesses noted. Each is examined for how well it addresses the multiple biological, chemical, and physical mechanisms and processes that cause odors or corrosion in collection systems. These mechanisms/processes include:

- Liquid phase sulfide generation
- Liquid-to-vapor H_2S mass transfer
- Natural liquid phase chemical and biological oxidation of sulfides
- Dissolved oxygen impacts on sulfide generation
- Liquid and vapor phase bulk transport of sulfides and H_2S, respectively
- Vapor phase H_2S-induced concrete corrosion

Several wastewater collection system models have been developed to facilitate the assessment of sulfide generation and potential release into the sewer headspace atmosphere. While several of the models rely on similar methods for approximating sulfide generation and liquid-to-vapor mass transfer, the methods for predicting ventilation rates and inclusion of concrete corrosion as an H_2S loss term are not consistent. An improved understanding of the fundamental principles associated with these two areas—natural ventilation of sewers and quantification of vapor phase H_2S loss associated with concrete corrosion—are therefore considered key areas for future research.

The existing knowledge base related to sewer ventilation is described in Chapter 6. The nature and extent of air exchange (ventilation) between the ambient atmosphere and headspace of sewers may be the most important variable affecting the generation and release of odorous and corrosive gases in gravity-flow sewers. Sewer ventilation is required to replenish the oxygen content in the headspace of sewers, and thus affects the dissolved oxygen content of wastewater. It can also affect the degree of condensation on sewer crowns (and hence sewer corrosion), and it defines the locations where odorous gases are released from the sewer system.

Despite the obvious importance of sewer ventilation to collection system odor and corrosion problems, there has been little progress related to a fundamental understanding of the competing factors that affect ventilation. Factors required to relate changes in wastewater flow, headspace above the liquid, or physical structure of sewer systems to sewer ventilation are needed. Improved knowledge in this area is critical to advancing integrated solutions to sewer odor and corrosion problems. Research has tended to evaluate specific collection systems and focus on solving site-specific odor problems. Full-scale field data often vary considerably from predicted values developed from laboratory pilot tests. None of the previous work attempts to define sewer headspace ventilation in terms similar to airflow in a duct and then relate those parameters to wastewater flow and interceptor characteristics. Furthermore, collection system leak-tightness, while being a critical ventilation parameter, has not been assessed in any of the work thus far. A specific research agenda related to sewer ventilation is described at the end of Chapter 6 and in the research gap summary Chapter 10.

In Chapter 7 we present current, successful, state-of-the-art techniques regarding liquid phase odor and corrosion prevention and provide information on how they work, mechanisms and key equations, and how they are being used globally. A proven approach to reducing both odor and corrosion inside the collection system requires a cost-effectiveness calculation and present worth value investigation before settling on an approach or implementing one in the collection system. Research gaps are provided for future research consideration. These gaps include: Life cycle analysis of collection system chemical addition impacts on downstream processes, pure oxygen treatment of gravity sewers, magnesium hydroxide odor control mechanisms other than pH adjustment, and liquid phase biological treatment. Details related to each knowledge gap are provided at the end of Chapter 7.

Traditional and innovative gas phase odor treatment approaches and equipment are presented in Chapter 8, with a focus on pump stations and other wastewater collection system locations or structures that could potentially emit odors into the surrounding atmosphere. Traditional and innovative approaches are explored for use at the various odor-emitting processes or structures, including chemical and carbon scrubbers, membrane reactors, biotowers, and biofilters. Innovative approaches include membrane reactors and biotechnology as well as combining traditional approaches with new ones to meet very high odor removal needs. Much information on these successful odor control approaches and applications is available. Insights on how and where to use these gas phase odor treatment systems throughout the collection system are provided. Specific research needed to fill current knowledge gaps include: identification of compound in sewer gas that lead to odor complaints, effectiveness of treatment systems for odorous gases other than H_2S, and effectiveness of biotechnology in cold climates.

Also presented, in Chapter 9, are corrosion mechanisms that have been described in the literature only recently; measures to control such mechanisms have been developed in parallel. Three such measures include adding coatings, most frequently on the crown of the pipe; lining the pipe wall; and installing corrosion-resistant pipe material. The many methods currently available to repair, rehabilitate, and replace wastewater collection systems are examined. Each method's appropriate uses and limitations are discussed, and the suitability of a given technology for a specific project is provided. This chapter also includes a discussion of chemical addition and ventilation approaches as means to protect and prevent corrosion forming compounds in the gas phase of the collection system. It was concluded that guidance is needed for agencies needing to provide pipeline corrosion protection for both new and existing installations. While many vendors may claim that their corrosion protection techniques are the most effective, objective data are needed. Pipe material corrosion resistance techniques should be compared to other techniques such as chemical addition.

Our literature search and evaluation initially identified 13 significant gaps in research and knowledge and suggests potential research to be undertaken to fill each knowledge gap. Table ES-1 summarizes those gaps and the projected costs of research for most of these gaps:

Table ES-1. Research Gaps and Their Projected Costs

Research Gap	Projected Cost ($)
1. Air movement and displacement in collection systems	212,731
2. Odorous and corrosive compounds found in collection systems	163,000
3. Effective treatment of non-H2S odorous compounds	151,900
4. Relationship between H_2S gas concentrations and corrosion rates	196,985
5. Impacts of collection systems' chemical dosing on the downstream treatment plant	100,000
6. Sulfide generation rates and the importance of substrates	117,000
7. The practicality and related costs of using oxygen treatment in gravity sewers	118,000
8. Biological treatment using enzymes and bacterial cultures and the effectiveness of these approaches	52,000
9. The mechanisms of magnesium hydroxide pH control	88,000
10. Design guidance for sizing air jumpers and related ventilation systems (may become part of the effort associated with Gap 1)	36,000
11. The effectiveness of biotechnology-based odor control systems in cold climates	143,000
12. Odor and corrosion impacts from fats, oils, and grease	75,000
13. The odor and corrosion effect of using sewers as reactor vessels to achieve partial wastewater treatment	192,000

Note: Cost is initial estimated cost including in-kind contributions. Final cost would be developed for higher priority research gaps that move forward.

A briefing held with the PSC allowed the initial list of 13 research gaps to be focused down to the six highest-priority gaps. A WERF subscriber survey was then completed in order to further refine this list and select the highest priority research gaps. Four top-priority research gaps were identified on the basis of this survey and review with WERF:

- Improving understanding of the nature of sewer system ventilation
- Improving understanding of the relationship between H_2S gas phase concentrations and corrosion
- Better defining the range of odor- and corrosion-causing compounds that come from collection systems (a subset of this topic being the desirability to better understand the impacts of fats, oils, and grease on odor- and corrosion-causing compounds in collection systems receiving high doses of fats, oils, and grease)
- Determining the effectiveness of liquid and gas phase treatment approaches for non-H_2S Odor compounds

On the basis of input and guidance from WERF, WERF subscribers, and utility owners the highest priority research gap areas will be pursued in following phase of this study within the limits of available scope and funding or will be pursued through collaborative research programs.