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Qualitative Evaluation of Greenhouse Gas Emission Footprints from Surface Excavation

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Abstract*: *With growing concerns about global warming and greenhouse gas (GHG) emissions, there is an urgent need to evaluate and reduce the carbon footprint (CF) of surface excavation (SE). CF are GHG emissions caused by an activity or event. It is expressed in terms of the amount of carbon dioxide (CO_2), or its equivalent of other emitted GHGs. Choosing an appropriate low-carbon emission method for SE is a vital task and involves environmental concerns due to several energy-consuming activities. Since essentially, every SE impacts the environment, it becomes very important to evaluate this impact and take necessary actions to minimize any negative consequence. The objective of this paper is to present a comprehensive overview on progress acquired over the years in understanding GHG emissions from SE and to discuss the steps in CF estimation. Publications were identified that reported GHG emissions and CF of SE over past 30 years. This literature review suggests that for most of the SE, the material production phase consumes a large amount of energy and is a major contributor of GHG emissions. Early phases of project planning should include appropriate ecological decisions consistent with the life-cycle assessment (LCA) and CF considerations. Pipe material and outside diameter should be considered during the SE to allow a detailed evaluation and reduction of their environmental impacts (EI). Incorporation of additional factors, such as cost and duration of the project into the environmental analysis is also recommended.*

Keywords*: *Carbon footprint, Environmental impacts, Greenhouse gas emission, Surface excavation.

I. INTRODUCTION

Pipelines are extremely important for modern society, as they are the medium for transportation of water, wastewater, oil, and gas. Throughout the world, the pipelines are facing a crisis due to rising population and lack of attention to its renewal and maintenance planning [1]. SE significantly impact the environment and carbon emissions, due to several energy-related activities, which include pipe material manufacturing, transportation, construction equipment use during SE, and operation and maintenance (O & M) [1, 2, 3, 4, 5]. Underground pipeline construction involves excavation to be performed very efficiently and accurately due to the existence of other utilities, including water pipes, cables, electrical power, gas pipes, and other obstacles adjacent to the wastewater pipe, which makes the work time-consuming and difficult [4, 5, 6]. This method however, adversely adverse impacts on the day-to-day life and activities of people and businesses around the underground construction project [5, 6, 7, 8]. These adverse impacts include breaking of the road pavement, road closures, traffic delays [9, 10, 11], loss of access to businesses and homes and unwanted noise and air pollution [4, 5]. The resulting traffic delays can cause air pollution and other EIs involved in the SE procedure should be considered [5, 6, 7, 8].

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The EIs from SE have been evaluated and compared economically and logistically but gave lacked environmental investigations [5, 6, 7, 8, 9, 10]. In fact, the SE are not environmentally sustainable, however, this assertion is limited to certain EI such as GHG emissions [5, 6, 7, 8] and limited pipeline construction activities without a comprehensive LCA [8, 9, 10, 11].

The objective of this paper is to present a comprehensive overview on progress acquired over the years in understanding GHG emissions from SE and to discuss the steps in CF estimation. Publications were identified from databases, such as such as ProQuest, Engineering Village, ASCE, and Google Scholar that reported GHG emissions and CF of SE over past 30 years.

II. GREENHOUSE GAS EMISSIONS

GHG emission analysis is becoming more popular in the construction industry, and it is also critical to estimate emissions for all pipeline projects. The investigation and quantification of the amount of GHG emissions were conducted during previous years in several studies, and various efforts to estimate emissions from SE operations can be found in the literature. Key models are the Environmental Protection Agency (EPA)'s Nonroad model [1], and the California off-road model. Researchers applied the EPA Nonroad model to estimate the emissions generated by equipment and transportation in a utility installation project employing SE. Project emissions were calculated by an emissions calculator based on the EPA model, and the site details and equipment usage hours that were collected onsite were used as inputs in the calculator to estimate the total number of emissions [12, 13]. The developed model could be used by policy makers to select the proper construction methods based on estimated emissions. This initial estimation would be helpful to narrow and reduce airborne pollution in future SE projects [14].

The EPA has developed an (Eq. 1.) to calculate the amount of GHG emissions produced by construction equipment [14].

Emissions i = EFi × HRS × HP × LF (Eq. 1.)

where, Emissions i is the emission amount generated by the equipment i (gallons), EFi is the emission factor for the impact i (g/hp-hr), i is the type of pollutant (CO_2, SO_2, NO_X, CO, PM, HC), HRS is the hours of use, HP is the average rated horsepower of the equipment, and LF is the load factor (operating hp/maximum rated HP).

Table 1 shows the EF equations used for construction equipment for HC, CO, NO_X, PM, CO_2, and SO_2 [14].

Table 1. EF Equations for Construction Equipment

Notation	Description	Equations
EF (HC, CO, NOx)	HC, CO, and NO_X EF	EF_{SS} × TAF × DF
EF (PM)	PM EF	EFSS × TAF × DF – S_{PMadj}
EF (CO_2)	CO_2 EF	44gCO_2/12gC × 0.87 × (BSFC × TAF × 453.6 − HC)
EF (SO_2)	SO_2 EF	64gSO_2/32gS × 0.01 × SO_x dsl × (BSFC × TAF × 453.6 × (1 − SO_xconv) − HC)

Note: EFSS: Steady-state emission factor; TAF: Transient adjustment factor; DF: Deterioration factor; BSFC: Brake-specific fuel consumption; SPmadj: Sulfur content adjustment to PM EF; SOxdsl: Episodic fuel sulfur percentage; and SOxconv: Fraction of fuel sulfur converted to PM.

The transportation footprint is calculated using (Eq. 2.) [14, 15]:

Emissionsti = EFi × n × (DO + DR) (Eq. 2.)

Where, Emissionsti is the transportation emission, EFi is the transportation EF from pollutant i (g/mi), n is the number of trips required to transport materials and equipment, DO is the one-way distance hauling to the site, and DR is the return distance from the site.

SE activities are increasing atmospheric concentration of CO_2 and other GHG released by human activities are warming the earth [14, 15, 16]. The mechanism is generally known as the "greenhouse effect" is what makes the Earth habitable. These activities have changed the chemical composition of the atmosphere through the buildup of GHGs primarily. These gases in the atmosphere act like the glass of a greenhouse, allowing the sunlight in and blocking heat from escaping [14, 15, 16]. CO_2 accounted for 82% of all human GHG emissions in the U.S. in 2013 [14, 15, 16]. The majority of CO_2 is released from fossil fuels, coal, oil, the gas used for electricity production, transportation, and industrial processes. Other important GHG include CH_4, N_2O, black carbon (BC), and various fluorinated gases. Although these gases are emitted in a smaller amount to the atmosphere compared to CO_2, they trap more heat in the atmosphere than CO_2 [14, 15, 16]. The most common and popular criteria used to describe sustainability efforts from the environmental viewpoint is the concept of CF. While GHGs exist naturally in the atmosphere, increases in their concentrations have been attributed to global warming or more accurately, climate change. For simplicity and understanding, the level of GHG emissions, or CF, is often expressed in terms of the equivalent amount of emitted carbon dioxide (CO_2EQ) [14, 15, 16, 17].

III. CARBON FOOTPRINT

CF is defined as a measure of GHG emissions from any activity or product such as SE and is generally considered to be a manufactured or artificial occurrence. GHG from a pipeline project can be emitted through the processes of transportation, site clearing, production and consumption or use of fuels and gas, and pipe materials manufacturing. While earlier studies focused only on GHG emissions as the guidelines and suggested to include all important GHGs in the calculation, CF has become an important tool for a comprehensive GHG account, over the pipelines' life-cycle [16, 17]. However, no definition, has been accepted yet, which clarifies this concept. There are different CF studies involved in the selection of gases and tiers [11, 12, 13, 14, 15, 16, 17, 18].

The steps that are suggested for CF estimation are discussed as follows: (1) Selection of GHGs, (2) Setting boundary, and (3) Collection of GHG emission data [14, 15, 16].

A. Selection of GHGs

Selection of GHGs from SE projects and the calculation of its CF mainly depends on the guideline followed, and on the method of pipeline construction activity for which CF estimation is being conducted. For example, during air emissions in the SE, CO_2 is predominant and other gases are almost negligibly emitted, so that only CO_2 emission measurement will be necessary [14, 15, 16].

While some studies include only CO_2 emissions in the estimation of CF, others include the measurement of emissions from six Kyoto gases [14, 15, 16, 17, 18, 19]. The guidelines and standards also suggest incorporating all other important GHGs and not only CO_2. In an Indianapolis, US based study, used CO_2 and CH_4 gases to calculate the CF [16, 17, 18, 19].

B. Setting Boundary

Setting boundary refers to the drawing of an imaginary line around the SE that will be used for calculating CF and emissions. It depends on the objective of the footprint estimation and characteristics of the entity for which CF will be estimated. The boundary must be selected to represent the construction organization [16, 17, 18, 19].

In case of joint SE projects, the concerned organization may take responsibility of the fraction of the GHG emissions for which it is responsible or might consider all the emission sources that are under its direct control, depending upon the need of CF estimation [19, 20].

Once the boundary is set, the operational boundary is selected to carry out the CF of a pipeline project. The operational boundary refers to the selection of the direct and indirect GHG emissions that are to be considered in the accounting. To facilitate the accounting process, three tiers have been suggested [16, 17, 18, 19].

Fig. 1 shows the three tiers in the CF estimation for SE. Tier I includes all direct emissions, including onsite emissions in the pipeline projects, tier II includes embodied emissions in purchased energy, and tier III involves other indirect emissions from pipe transportation, energy activities, and disposal of pipes, which are not included in tiers I and II [16, 17, 18, 19, 20, 21].

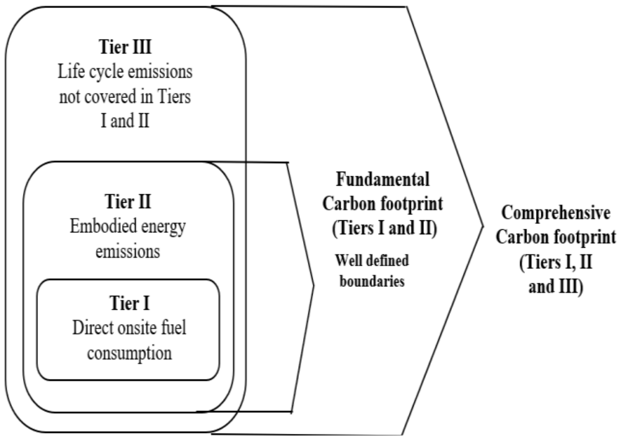

Fig. 1: Boundary Conditions for CF Estimation

Tier II, however, does, include indirect emissions, embodied in energy production or transmission and distribution of pipelines. End user emissions are out of scope of tier II whereas tier III covers all the embodied emissions within the specified boundary for SE. However, tier III has been vaguely defined and most pipeline CF studies limit the study to tier I and tier II as it becomes too complex to accurately estimate CF beyond tier II. Nonetheless, it becomes important to learn as how much control over GHG emissions can be made beyond tier II [16, 17, 18, 19, 20, 21].

Therefore, most of the GHG accounting standards including GHG protocol; PAS-2050, and other based organizations have retained the option of including tier III. Advancement in the tracking and management of GHG emissions is expected to promote tier III accounting and reporting [16, 17, 18, 19].

Thus, CF can have two main components: (1) basic or primary, which refers to CF calculated from direct emissions and emissions embodied in the purchase of energy, and (2) full CF, which includes all the direct and indirect emissions [16, 17, 18, 19].

C. GHG Data Collection

GHG data pertaining to emissions from SE can be collected directly onsite through real-time measurements or by estimations based on EFs and models. The choice of suitable method depends on the objective, which could be for voluntary, mandatory, or internal use, and considering credibility, feasibility as well as cost and capacity. Generally, EFs and models are the most preferred and used techniques for GHG data collection [16, 17, 18, 19].

For pipelines, GHG emissions are calculated by EFs and models using data based on fuel consumption, energy, and other inputs that allow an estimate of CO_2 emissions. EFs are available for a wide range of processes and are used in GHG protocol, Publicly Availability Specification (PAS-2050), Intergovernmental Panel on Climate Change (IPCC-2006), and EFs are developed in many countries with national inventories under United Nations Framework Convention on Climate Change (UNFCCC), United States Environmental Protection Agency (USEPA), United Kingdom Department for Environment, Food and Rural Affairs (UK DEFRA), etc. [16, 17, 18, 19, 20, 21].

However, for other sources and fugitive emissions, direct measurements should be made [18].

Besides onsite measurement of emissions from pipelines installation, other data sources and global databases are now available. A CO_2 emissions database from different countries has been developed under a global trade analysis project (GTAP) [16, 17, 18, 19].

Other reliable data sources include national GHG inventories and other public offices maintaining a record of fuel and energy consumption, International Energy Agency, United Nations Development Program (UNDP), etc. [16, 17, 18, 19].

While direct measurements are accurate and precise, their cost and application may be prohibitive [16, 17, 18, 19]. Advanced measurement and monitoring systems including geographic information system (GIS), remote sensing (RS), and optical measurement systems are now being combined with individual GHG inventories to provide a comprehensive source (United States Climate Change Technology Program [16, 17, 18, 19].

To improvise accuracy of ground-based monitoring networks in distribution pipelines, satellites have now been launched to monitor sources and sinks of CO_2 and other GHGs uniformly [16, 17, 18, 19]. Japanese GHG, launched in 2009, is monitoring GHGs, while a joint project of National Aeronautics and Space Administration (NASA) and US Department of Energy designated "Vulcan" is quantifying GHG emissions due to fossil fuel burned in North America [16, 17, 18, 19, 20, 21].

RS and GIS are extensively in use for large and relatively less accessible areas [18]. In addition, reproducibility, verifiability, and systematic documentation are important for data collection of emissions from SE projects [17, 18, 19].

IV. DISCUSSION

For sustainable SE, economic, environmental and societal factors need to be combined and can be expressed using three overlapping ellipses, as shown in Fig. 2. There is also an understanding that social and economic impacts will eventually be constrained or controlled by environmental considerations when limiting values of available materials required to sustain economic growth are reached [22, 23].

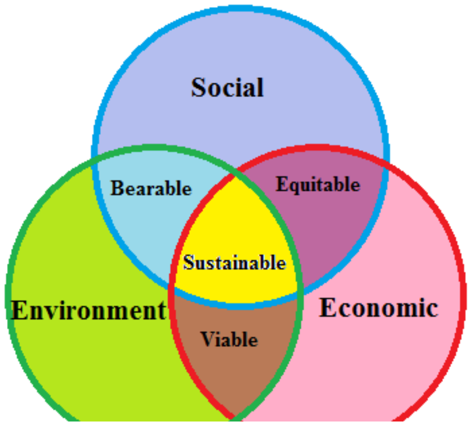

Fig. 2 Three Pillars of Sustainability

Common to both the public policy and business perspectives is recognition of the continued need to support a growing, often global, economy while reducing the social, environmental and economic costs of growing underground infrastructure. Sustainable design and construction of pipelines can be facilitated or guided by public policies that integrate environmental, economic, and social values in the decision-making process [22, 23].

As said above, successful, long-term implementation of sustainable growth and development for underground pipelines reflect on the synergies between the business and the environmental issues and not on trade-offs, credits or mitigation banking so often touted as "green" solutions. It is recognized that there is a need to get to truly sustainable project development but also that there is the practicality (i.e., obtaining public acceptance) that this evolution and thus the level of improvement will occur in steps [22, 23, 24].

- Conventional - state of the practice, specific sustainability considerations not addressed; i.e., "business as usual [22]."
- Improved - incremental improvements above conventional practice reducing impacts previously expected
- Sustainable - achieves equilibrium with environmental and resource limitations without adverse impacts on society or excessive costs; i.e., "not making things worse [22, 23, 24]."
- Restorative - restores resources and ecological capacity, improves economic and social systems; i.e., "investing in the future [22, 23]."

Further, four parameters specific to pipeline infrastructure sustainability can be defined as follows:

- Better Management of water and wastewater utilities can encompass practices like asset management and environmental management systems. Consolidation and public/private partnerships could also offer utilities significant savings [23].
- Full Cost Pricing so that utility rates reflect the true cost of service and maintaining its assets.
- Efficient Water Use is critical, particularly in those parts of the country that are undergoing water shortages. Utilities provide incentives through its water rates to encourage more efficient use of water by customers to protect limited water resources. Water waste includes not just leakage but excessive flushing to overcome poor water quality. Utilities need to promote water conservation not water use.
- Watershed Approaches that look more broadly at water resources in a coordinated way. Regional approaches can often be more efficient and reduce duplication of facilities.

Within a global economy, the basic tenants of sustainable development need to be applied on a global scale. One consequence of over-development are the inarguable consequences of climate change. While climate change may not be totally attributable to human activities, there can be little doubt that they are a contributing factor over which we have some control. It has been recognized for some time that human beings use world's resources faster than they can be replaced, as illustrated in Fig. 3 [22, 23, 24, 25, 26, 27, 28, 29].

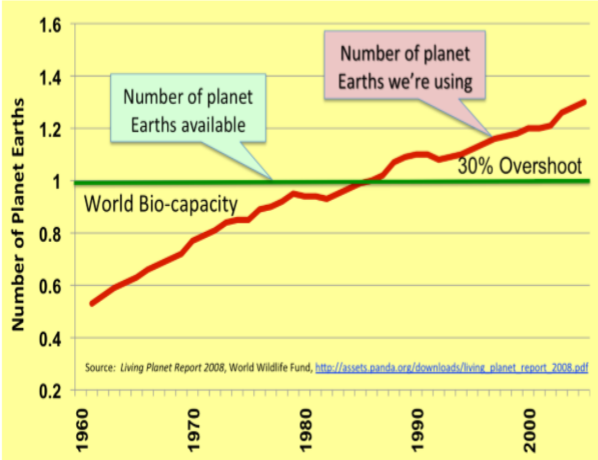

Fig. 3 Utilization Rate of Resources

V. CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

It can be concluded that while the study of CF and GHG emissions can be used as a quantification tool to measure the sustainability of SE, it does not measure the social and economic impacts. As a result, only an incomplete study of the sustainability impacts of the SE is provided because of many unknowns that are subjective by nature. Therefore, there is a need to devise a fact-based, scientific, and sustainable SE methodology, even if incremental at first, that helps to balance the many unknowns and give a comprehensive life-cycle environmental analysis. Since the use of CF to quantify the sustainability of SE does not provide any measure of social or economic impact, cooperation between the public and private entities involved in the SE project becomes important to offset the short-term gains of non-sustainable solutions at the cost of long-term EIs.

VI. ACKNOWLEDGMENT

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VII. ABBREVIATIONS AND ACRONYMS

CH_4 = Methane
CO_2EQ = Carbon dioxide equivalent
DO = One-way distance hauling to the site
DR = Return distance from the site
EF = Emission factor
EFi = Emission factor for the impact i
Emissions i = Emission amount generated by equipment i
HRS = Hours of use
EFZM = Zero-mile emission factor
NOX = Oxides of nitrogen
SOxdsl = Episodic fuel sulfur percentage
SOxconv = Fraction of fuel sulfur converted to PM.
SPmadj = Sulfur content adjustment to PM emission factor

REFERENCES

1. S. T. Ariaratnam and S. S. Sihabuddin, "Comparison of emitted emissions between trenchless pipe replacement and open cut utility construction," *Journal of Green Building*, 4(2), 2009, pp. 126-140.
2. ASCE, Guidelines for the Sustainable Design of Pipelines, Reston, VA, 2019.
3. M.A. Brown, F. Southworth, and A. Sarzynski, "The geography of metropolitan carbon footprints," *Policy and Society*, 27, 2009, pp. 285–304.
4. V. Kaushal and S. P. Guleria, "Geotechnical Investigation of Black Cotton Soils," *International Journal of Advances in Engineering Sciences*, Vol. 5, Issue 2, 2015.
5. Carbon Trust, "Carbon footprint measurement methodology," version 1.1. *The Carbon Trust*, London, UK, 2007.
6. Carbon Trust, "Carbon footprinting," *An introduction for organizations*, 2007.
7. V. Kaushal, M. Najafi, J. Love and S. R. Qasim, "Microbiologically Induced Deterioration and Protection of Concrete in Municipal Sewerage System: A Technical Review," *Journal of Pipeline Systems Engineering and Practice*, ASCE, 2020, Vol. 11, Issue 1.
8. CDP, "Carbon disclosure project report 2008: Global 500, on behalf of 385 investors with assets of $57 trillion," *Carbon Disclosure Project*, 2008, available online at http://www.cdproject.net/reports.asp.
9. L. Chilana, A. Bhatt, M. Najafi and M. Sattler, "Comparison of carbon footprints of steel versus concrete pipelines for water transmission," *Journal of the Air & Waste Management Association*, 2016, 66(5), pp. 518-527.
10. L. Craeynest and D. Streatfeild, "The World Bank and its carbon footprint: Why the World Bank is still far from being an environment bank," *World Wildlife Fund*, 2008.
11. A. Dada, T. Staake, and E. Fleisch, "The potential of UBICOMP technologies to determine the carbon footprints of products," *Proc.* Sixth international conference on pervasive computing, 19-22 May 2008, Sydney.
12. ISO, "ISO 14040: Environmental Management, Life Cycle Assessment—Principle and Framework. International Organization for Standardization (ISO)," Ginevra, Switzerland, 2006.
13. ISO, "ISO 14044: Environmental Management, Life Cycle Assessment—Requirements and Guidelines." Proc. International Organization for Standardization (ISO)," Ginevra, Switzerland, 2006.
14. V. Kaushal, M. Najafi, M. Sattler and K. Schug, "Review of Literature on Chemical Emissions and Worker Exposures Associated with Cured-In-Place Pipe (CIPP) Installation," *Proc.* ASCE Pipelines 2019, Nashville, TN.
15. S. Mohit, M. A. N. Monfared, C. Kang A. Bayat, "Comparative study of greenhouse gas emissions from hand tunneling and pilot tube method underground construction methods." *Journal of Green Building*, 2017, 12(4), 54-69.
16. M. A. N. Monfared, "Comparison of Trenchless Technologies and Open Cut Methods in New Residential Land Development," *Master's Thesis*, University of Alberta, Canada, 2018.
17. M. Najafi, *Trenchless technology: Pipeline and utility design, construction, and renewal*, McGraw Hill Professional, 2005.
18. D. Pandey, M. Agrawal and J .S. Pandey, "Carbon footprint: current methods of estimation," *Environmental monitoring and assessment*, 2011, 178(1-4), pp. 135-160.
19. J. Patel, "Green sky thinking," *Environment Business*, 2006, 122, 32.
20. S. Sihabuddin and S.T. Ariaratnam, "Quantification of carbon footprint on underground utility projects," *Proc.* Construction Research Congress 2009: Building a Sustainable Future, 2009, pp. 618-627.
21. J. Simicevic and R. L. Sterling, "Guidelines for Pipe Bursting US Army Corps of Engineers," Engineering Research and Development Center. *Trenchless Technology Center Report*, Ruston, Louisiana, 2001.
22. V. Kaushal, M. Najafi, and J. Love, "Qualitative Investigation of Microbially Induced Corrosion of Concrete in Sanitary Sewer Pipe and Manholes," *Proc.* ASCE Pipelines 2018, Toronto, Canada, pp. 768-775.
23. J. Strutt, S. Wilson, H.L. Darby, A. Shaw, A. Byers, "Assessing the carbon footprint of water production," *Journal of American Water Works Association*, 2008, 100(6), 80–91.
24. V. Kaushal, "Earthquake Resistant Construction," *Engineering Sciences International Research Journal*, Vol. 2, Issue 1.
25. P.V. Sundareshwar, R. Murtugudde, G. Srinivasan, J. Singh, J.K. Rajmesh and R. Ramesh, "Environmental monitoring network for India," *Science*, 2007, 316, 204–205.
26. V. Kaushal, "Comparison of Environmental and Social Costs of Trenchless Cured-in-Place Pipe Renewal Method with Open-cut Pipeline Replacement for Sanitary Sewers," *Ph.D. Dissertation*, University of Texas at Arlington, TX, USA, 2019.
27. G. Venkatesh and H. Brattebo, "Energy consumption, costs and environmental impacts for urban water cycle services: Case study of Oslo (Norway)," *Energy*, 2011, 36(2), 792–800.
28. T. Wiedmann and J. Minx, "A definition of carbon footprint," *ISAUK Research Report 07-01*, Durham, ISAUK Research & Consulting, 2007.
29. V. Kaushal, M. Najafi, M. Sattler, and K. Schug, "Evaluation of Potential Release of Organic Chemicals in the Steam Exhaust and Other Release Points during Pipe Rehabilitation Using the Trenchless Cured-In-Place Pipe (CIPP) Method," *Proc.* North American Society for Trenchless Technology (NASTT) No-Dig Conference, Chicago, IL, 2019.

AUTHOR'S PROFILE

C. P. Kaushal obtained his Doctor of Philosophy (Ph.D.) degree in Chemistry from Himachal Pradesh University, Shimla, India in 1989. He has more than 30 years of teaching experience and has several publications in peer-reviewed/refereed Journals of National and International repute. He is also one of the co-authors of two book chapters published by Springer. His research areas include environmental chemistry, irreversible thermodynamics, electrochemistry and chemical kinetics. Dr. C. P. Kaushal is presently working as an Associate Professor in the Department of Chemistry at Maharaja Lakshman Sen Memorial (MLSM) Post Graduate College, Sundernagar, H.P., India. He lives in Sundernagar, H.P.