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Emission factor estimation for oil and gas facilities

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ABSTRACT

Fugitive emission rate quantification in an oil and gas facility is an important step of risk management. There are several studies conducted by the United States Environmental Protection Agency (USEPA) and American Petroleum Institute (API) proposing methods of estimating emission rates and factors. Four major approaches of estimating these emissions, in the order of their accuracy, are: average emission factor approach, screening ranges emission factor approach, USEPA correlation equation approach, and unit-specific correlation equation approach. The focus of this study is to optimize the USEPA correlation equations to estimate the emission rate of different units in an oil and gas facility. In the developed methodology, the data available from USEPA (1995) is used to develop new sets of equations. A comparison between USEPA correlation equations and the proposed equations is performed to define the optimum sets of equations. It is observed that for pumps, flanges, open-ended lines, and others, the proposed developed equations provide a better estimation of emission rate, whereas for other sources, USEPA equations supply the better estimate of emission rate.

Keywords: Oil and gas industry; Emission factor; Linear regression; Non-linear regression

1. Introduction

Fugitive emissions are any type of leak from the sealed surfaces of equipment associated with the process industries, mainly oil and gas facilities (USEPA, 2007). The major emissions are hydrocarbons; aromatic hydrocarbons including benzene, toluene, ethyl-benzene, and xylene; non-aromatic hydrocarbons including methane, ethane, propane, butane, pentane, and hexane (API, 1993a).

Valves, pump seals, connectors, flanges, and open-ended lines are the main sources of equipment leaks in oil and gas facilities while instruments, loading arms, pressure relief valves, stuffing boxes, and vents are considered “others” (API, 1993a).

To estimate the emission, a factor representing the relationship between the emission and the activity associated with the release of that particular emission or emission factor, is used (Eq. (1)).

$$E = A \times EF \times \left(1 - \frac{ER}{100}\right) \quad (1)$$

where *E*, emission (mass); *A*, activity rate (mass, volume, distance, or duration of the activity emitting the pollutant); *EF*, emission factor (mass/mass, volume, distance, or duration of the activity emitting the pollutant) and *ER*, overall emission reduction efficiency (%).

Emission factors are represented by units such as the mass of pollutant per unit mass, volume, distance, duration of activity, or other aspects associated with the activity of concern.

Emission factors are applied for a variety of situations, such as emission estimates for inventories associated with large industries. The inventories are also applicable in ambient dispersion modeling and analysis, management methodologies, and screening sources where required (USEPA, 2010).

Generally, there are four approaches to equipment emission estimation. These approaches, in order of increasing the accuracy, are the average emission factor approach, screening range approach, EPA correlation approach, and unit-specific correlation approach. The first two methods, the average emission factor and the screening range approach, estimate emissions by combining the emission factors with equipment

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counts. The EPA correlation factor estimates the emissions using the measured concentrations (screening values) of different equipments and correlation equations. In the last, the unit-specific correlation approach, the measured screening and leak rate data of a selected set of equipment components are used to develop the correlation equations. Subsequently, the leak rate is estimated using these correlation equations (USEPA, 1995).

Studies on emission factor development have been conducted on refineries, gas plants, marketing terminal equipments, and oil and gas production facilities. Studies on refineries' fugitive emissions were based on equipment leak data collected from 13 refineries. The collected data has been used to develop average emission factors and correlations. The above studies defined the components as valves, pumps, and pressure relief valves which operate in gas/vapor, light liquid and heavy liquid services (USEPA, 1995). In another study, based on the data screened by EPA and API from six gas plants, the average emission factors including emissions of ethane and methane have been developed (Dubose et al., 1982). In the API (1993a), the data screened from four marketing terminals has been used to develop new average emission factors, default zero emission factors, and emission correlation equations for the components of petroleum marketing terminals. In addition to the above, API (1993b, 1995) provided two more reports, including data from 24 oil and gas production facilities. The services in these facilities were gas/vapor, light liquid, and heavy liquid streams in the different components including connectors, flanges, open-ended lines, pumps, valves, instruments, loading arms, pressure relief valves, stuffing boxes, vents, compressors, dump lever arms, diaphragms, drains, hatches, meters, and polished rods. The results from these studies were used to develop emission correlation equations in two different categories of onshore and offshore oil and gas production facilities (API, 1993b, 1995). In the last, data from refineries, marketing terminals and oil and gas production facilities was used to develop the new correlation equations, which are applicable in the whole petroleum industry. New equations are in six different equipment categories: valves, pump seals, connectors, flanges, open-ended lines, and others (USEPA, 1995).

The focus of this study is to optimize the emission rate estimation with the use of EPA correlation equations. The EPA approach of developing correlation equations will be outlined and a non-linear regression conducted. In this approach, the parameters for the non-linear regression are estimated with the target of minimizing the total squared errors. Subsequently, the new approach is applied to a case study and the results are compared with those of EPA to optimize the selection of the most appropriate equations.

2. Correlation equation development methodology

For a particular equipment type, an equation is developed to estimate the leak rate as a function of screening value which is the screened concentration of emission from the equipment. Compared with two previous methods, this approach is a strong function of the screening value, which provides an auditable basis and enhances emission rate prediction ability (USEPA, 1995).

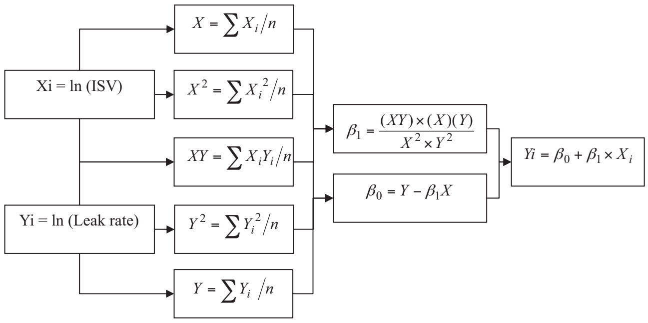

Fig. 1 – Application of linear regression with ISV and emission rate.

2.1. *EPA correlation equation approach*

According to EPA protocol (USEPA, 1995), when developing correlation equations, two sets of data are required:

- Individual Screening Value (ISV) which is the screened concentration of emission from the equipment with unit of ppmv.
- Emission Leak Rate (kg/h).

The natural logarithm of both data (screening value (ppmv) and leak rate (kg/h)) is applied as these values span several orders of magnitude and are not normally distributed. Subsequently, simple linear regression is performed as follows (USEPA, 1995):

$$Y_i = \beta_0 + \beta_1 \times X_i \tag{2}$$

where Y_i and X_i are the natural logarithm of the leak rate measured by bagging equipment piece *i* and the natural logarithm of the screening value for equipment piece *i*, respectively. The intercept and the slope of the regression line (β_0 and β_1) are calculated as explained in Fig. 1.

Finally, Eq. (2) is converted from log-space to arithmetic space as follows:

$$\text{Leak rate (kg/h)} = \text{SBCF} \times \text{Exp}(\beta_0)(\text{ISV})^{\beta_1} \tag{3}$$

where SBCF is a function of the mean square error of the correlation in log-space. The equation for this factor is as follows (USEPA, 1995):

$$\text{SBCF} = 1 + \frac{(m-1)\times T}{m} + \frac{(m-1)^3 \times T^2}{m^2 \times 2! \times (m+1)} + \frac{(m-1)^5 \times T^3}{m^3 \times 3! \times (m+1) \times (m+3)} + \cdots \tag{4}$$

where T = (MSE/2) × ((ln 10)^2) when regression performed using base 10 logarithms; T = (MSE/2) when regression performed using natural logarithms; MSE = mean square error from the regression; ln 10 = natural logarithm of 10; and *M* = number of data pairs − 1.

2.2. *Approach used in present study*

In some cases of nonlinear models, the equation is transformable to a linear model. A good example of this situation is the EPA correlation equation format ($Y = aX^b$) where by obtaining the natural logarithm of both sides and converting the