CHEMICAL ENGINEERING TRANSACTIONS

VOL. 97, 2022

A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.cetjournal.it

Guest Editors: Jeng Shiun Lim, Nor Alafiza Yunus, Jiří Jaromír Klemeš

ISBN 978-88-95608-96-9; **ISSN** 2283-9216

DOI: 10.3303/CET2297084

Field Measurement and Dispersion Modelling of Hydrogen Sulphide for Recycled Paper Mill in Malaysia

Li Yee Lim[a], Cassendra Bong[a], Wai Shin Ho[a,*], Haslenda Hashim[a], Mohd Rozainee Taib[a], Pang Soon Ng[a], Keng Yinn Wong[b]

[a]School of Chemical and Energy Engineering, Universiti Teknologi Malaysia (UTM), 81310, UTM, Johor Bahru, Johor, Malaysia
[b]School of Mechnical Engineering, Universiti Teknologi Malaysia (UTM), 81310, UTM, Johor Bahru, Johor, Malaysia
hwshin@utm.my

Hydrogen sulphide (H_2S) is a well-known environmental pollutant from the industrial sector due to its unpleasant odour and high toxicity. It can post health threat at a low threshold exposure limit, with concentration as low as 0.01-1.5 ppm. In the pulp and paper mills, a significant amount of total reduced sulphur (TRS) is generated during the pulping and bleaching process. The TRS contains various pollutants such hydrogen sulphide (H_2S), methyl mercaptan and dimethyl. For recycled paper mills, since the collected papers did not undergo the pulping and bleaching processes, the pollutant produced is mainly H_2S. Due to its high toxicity and low threshold limit, early H_2S detection and understanding its air dispersion pattern are important to reduce the potential health risk imposed by H_2S to the local workers and residence of the surrounding areas. However, the commonly used odour unit might not be sufficient to represent the specific concentration of H_2S. There has also been limited studies on the H_2S dispersion modelling in Malaysia. Thus, in this study, a H_2S dispersion modelling was performed at a recycled paper mill in Malaysia, with H_2S concentration (μg/m^3) as the odour indicator, to understand the changes in H_2S concentration at different distances from source and identify potential health risk. Firstly, air samples were collected and analysed to identify the emission hotspots. The American Meteorological Society/Environmental Protection Agency Regulatory Model (AERMOD) was then used to determine the dispersion pattern of H_2S and its concentration across the surrounding air. Wind data for 2 y was recorded and input for the modelling. Both the gas sampling study and dispersion modelling showed that the concentration of H_2S was below the threshold limit at a distance of 50 m from the emission source, which was the effluent sludge holding tank. It is unlikely that the H_2S emission from the recycled paper mill would lead to odour or health complaints to the surroundings.

1. Introduction

Odour emission is defined as mixtures of various chemicals that interact to produce what human detect as smell (UK Institute of Air Quality Management, 2018). The factors that affect the perception of annoyance or nuisance of smell are the frequency of odour occurrence, duration of exposure to odour, odour offensiveness and receptor's expectation and tolerance (Greenberg et al., 2013). Odour emission can be an important source of environmental nuisance. Unpleasant odour not only affect public amenity and the community's life quality, but also attract insects, rodents and birds (Scaglia et al., 2011).

Industrial wastewater treatment plant can be a significant source of odour. Some common pollutants are ammonia (NH_3) and hydrogen sulphide (H_2S). The former is produced from the decomposition of protein and the latter is released during the anaerobic decomposition of sulphur-containing proteins (Lewkowska et al., 2016). One of the industries with such concern is the pulp and paper manufacturing. The pulping of wood and bleaching processes produces a significant amount of total reduced sulphur (TRS) (Cartelle et al., 2016), which includes pollutants such as hydrogen sulphide (H_2S), methyl mercaptan, dimethyl sulphide, and dimethyl disulphide. Compared to kraft paper mills, recycled paper mills do not have pulping of wood and bleaching process. The main pollutant is thus H_2S, which comes from the effluent treatment plant. Odour threshold limit

Paper Received: 9 September 2022; Revised: 4 October 2022; Accepted: 7 October 2022
Please cite this article as: Lim L.Y., Bong C., Ho W.S., Hashim H., Taib M.R., Ng P.S., Wong K.Y., 2022, Field Measurement and Dispersion Modelling of Hydrogen Sulphide for Recycled Paper Mill in Malaysia, Chemical Engineering Transactions, 97, 499-504 DOI:10.3303/CET2297084

for H_2S can be at concentration as low as 0.01-1.5 ppm (10 – 1,500 μg/m^3) , with recommended exposure limit (NIOSH) at 10 ppm, up to 10 min (OSHA, 2022). Due to the potential health hazard of H_2S at lower concentration, it is thus important for its early detection with high accuracy and understanding its dispersion pattern across the surrounding air.

The assessment of odour concentration is important for odour control operations and to minimize its negative impact to the nearby life quality. Odour is generally measured with human nose as detector. This method can be direct and with ease of implementation, but it does not directly indicate the odour level, i.e. the H_2S concentration. In current standard of procedure, odour assessment uses the Odour Unit (OU) to indicate the intensity of odours. Based on European standard, 1 OU_E is the amount of odourant(s) evaporated into 1m^3 of neutral gas. Odour assessment often just reports the ground level OU without further validation on field. On the other hand, odourants such as H_2S can spread over very large distances, which its concentration could be diluted below their olfactory detectability thresholds.

Dispersion modeling can effectively be used to predict the dispersion of odours by using suitable odour emission data and to present a link with odour complaints. Secondly, it is useful to estimate the maximum odour emissions that is allowed from a location, thus reducing odour complaints. One of such models is the American Meteorological Society/Environmental Protection Agency Regulatory Model (AERMOD) dispersion model. Dinçer et al. (2020) performed dispersion modelling and air quality measurements, focusing on H_2S and NH_3 as the two main odorous compounds from wastewater treatment plants, using AERMOD. The model showed that odour concentrations exceeding 10 OU/m^3 levels that can be measured olfactometrically do not create an odour impact on local residents but suggested that odour treatments are required due to the odour concentrations of waste treatment plant units above the limit values. Moreno-Silva et al. (2020) also estimated the H_2S emission rates from a reservoir where AERMOD model was used to identify the contribution of the reservoir on H_2S concentration in urban area. The results showed the applicability of using AERMOD model and flux chamber measurements in predicting H_2S behaviour.

Malaysia pulp and paper chemicals demand was at 0.15 Mt in 2020, with a growing rate of 3.92 % till 2030 (ChemAnalyst, 2021). Based on the authors' literature review, the reports of H_2S odour are in OU and rarely been represented on its own. There is a need of more insight on the H_2S dispersion behaviour in the air in order to minimize potential health impacts and improve the odour management at site. This study focuses on the case study of a recycled paper mill located in Malaysia with daily 800 t paper recycled. Firstly, an on-site air sampling and H_2S measurement were carried out. Next, the AERMOD was used for the modelling of odour dispersion. In this study, an improved procedure is proposed where air dispersion modelling is conducted in concentration of H_2S (m^3/s) instead of OU/s. Upon obtaining the simulated ground level concentration result using Gaussian Plume Model, the result is then compared with the concentration of an air sample collected from the emission source for validation.

2. Methods

2.1 On-site odour signature gas (H_2S) monitoring

H_2S monitoring was conducted to monitor the H_2S dispersion from the odour source. Odour source identification was done to identify the emission hotspots, include outthrow storage area, equalisation tank (incoming effluent area) and primary effluent sludge bolding tank. The primary effluent sludge holding tank was found to give the most significant odour among all units. To reduce the odours, tank cover and neutraliser were applied. The H_2S dispersion was then measured by sampling the H_2S from the primary sludge holding tank, followed by 20 m and 50 m downwind from the sources. The measurement was conducted in accordance to the Method 701: Determination of Hydrogen Sulfide in Air, Methods of Air Sampling and Analysis 3rd Edition (Lodge, 1988).

2.2 Odour dispersion modelling

AERMOD was used for the modelling of odour dispersion. According to US EPA (2022), to perform the odour dispersion modelling using AERMOD, following data input are required: upper air and hourly surface meteorological data, terrain and building input (surface characteristics describing the land use surrounding the site and the layout of the nearby buildings (Figure 1)) and define receptor locations (data input not provided as it is confidential). The chemical compound modelled was H_2S as the odour indicator. The H_2S emission rate with and without the neutraliser spraying were calculated. The modelling was conducted within 3 km radius with higher resolution, i.e. receptor spacing of 25 m × 25 m. The humidity recorded from the area were 82 -86 %. Wind data such as wind direction and wind speed were recorded from 1/1/2018 to 31/12/2020. Figure 1 shows the observations for the wind speed and wind direction over a 2-y period.

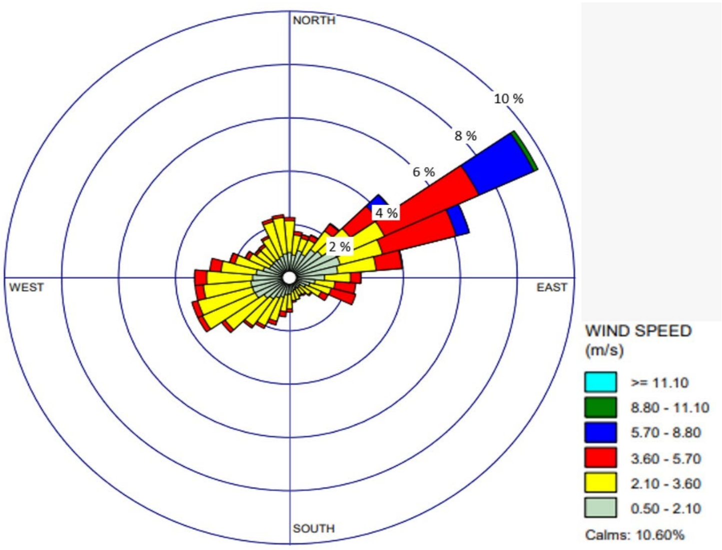

Figure 1: Wind data collected for 2 y around the recycled paper mill

The input data for the modelling is as follows:

A. Odour sources (primary effluent sludge holding tank 1 and 2)

<u>Primary effluent sludge holding tank 1</u>

Tank gab	:	11 m × 0.4 m = 4.4 m^2
Height from ground	:	3.5 m
Coordinates	:	Confidential

<u>Primary effluent sludge holding tank 2</u>

Tank gab	:	24 m × 0.4 m = 9.6 m^2
Height from ground	:	5.5 m
Coordinates	:	Confidential

B. Surrounding buildings

Several tall buildings exist on the south west area from the primary effluent sludge holding tanks. In addition, holding tank 1 is located between two clarifier (Building 3 and 4) that is taller than the holding tank. Figure 2 shows the Building Modelled in AERMOD with the location of the odour sources and the specifications of the surrounding building, with the red cross marks represent the holding tanks.

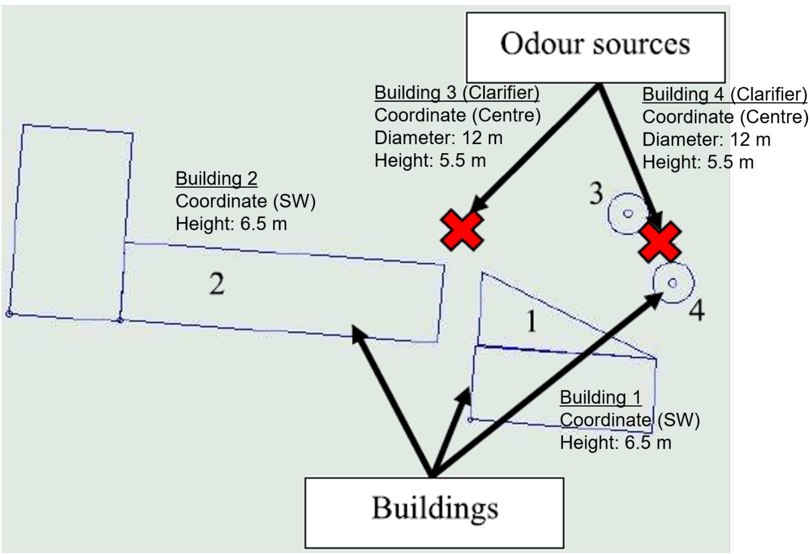

Figure 2: Building input in AERMOD with the location of the odour sources and the specification of the surrounding buildings.

3. Results and discussions

3.1 On-site odour signature gas (H_2S) monitoring

The H_2S concentration sampled at three different distances from the emission source is presented in Table 1. The use of neutraliser showed more promising effect in reducing the H_2S concentration at source, with 17 % reduction. At a distance of 20 m from source, the effect of neutraliser was halved. At a distance of 50 m from source, the effect of neutraliser was negligible. This might pose some health threats for workers on site due to the health hazard of H_2S at low concentration and under long-term exposure. The hazard concentration of H_2S has been reported to be 696,000 μg·m^{-3} – death after 30 min (by OSHA) and as low as 0.2 μg·m^{-3} (by WHO). As presented by Tong et al. (2017), H_2S was considered as one of the most serious gaseous pollutant from paper and pulp mills in China. All the detected H_2S data on the 30 sampling sites from 5 different mills were exceed the emission standard of 60 μg·m^{-3} by Chinese government. For the neighbouring community, the nearest human sensitive receptor was approximately 350 m away from the odour source. Thus, the impact of the odour to the human sensitive receptors outside of the plant is considered to be not significant.

Table 1: Concentration of H_2S at primary effluent sludge holding tank and 20 and 50 m downwind from the tank.

Distance from source (m)	Concentration of H_2S (μg/m^3)	
	With neutraliser spraying	Without neutraliser spraying
0 (at source)	514.63	622.35
20	4.43	11.68
50	0.00	0.01

3.2 Odour dispersion modelling

The following two figures show the modelling result from AERMOD model on H_2S dispersion pattern with neutraliser spraying after 1 h and 24 h of exposure. Figure 3 gives the dispersion pattern at a closer view (up to 500 m) while Figure 4 is at a broader view (up to 1,200 m).

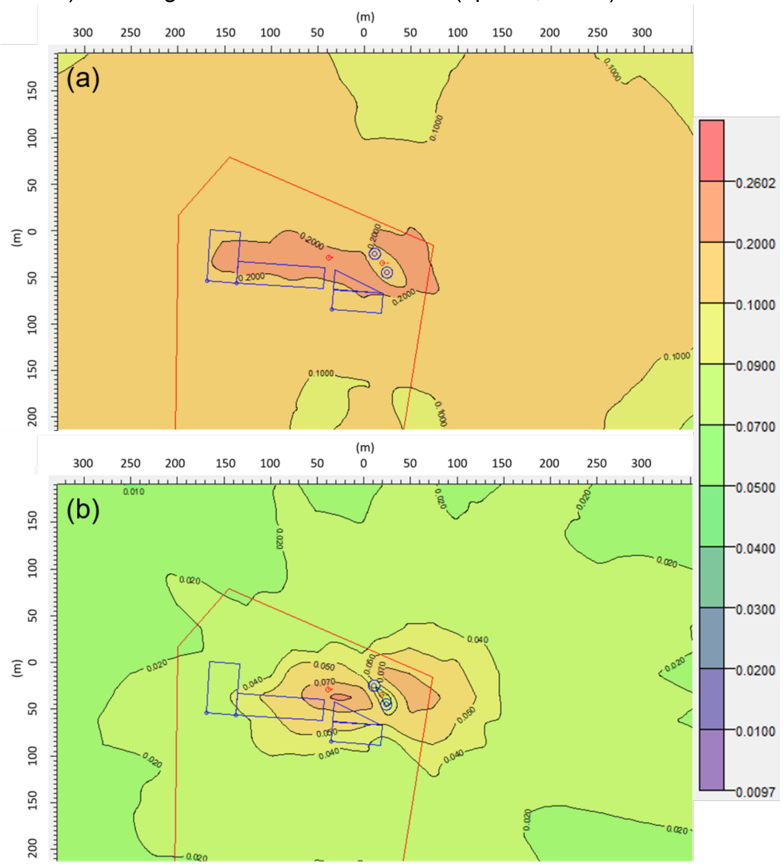

Figure 3: (a) 1 h and (b) 24 h average ground level concentration of H_2S (closer view)

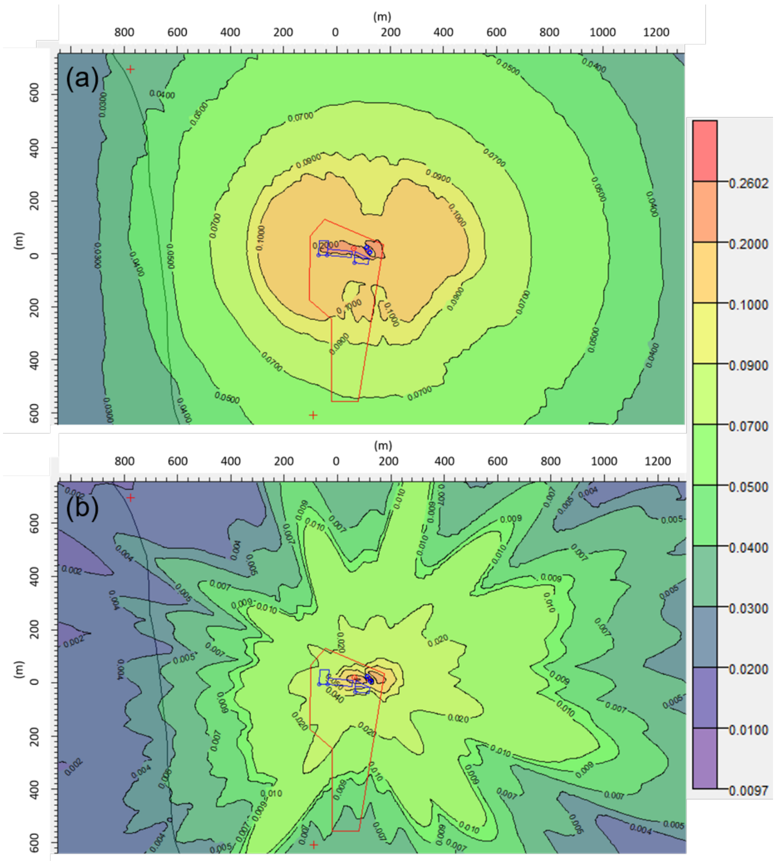

Figure 4: (a) 1 h and (b) 24 h average ground level concentration of H_2S (farer view)

The H_2S emission rates calculated from the primary effluent sludge holding tank 1 and 2 using the AERMOD were 5.867 × 10^{-6} and 7.153 × 10^{-6} $g{\cdot}s^{-1}m^{-2}$ with neutraliser and 7.831 × 10^{-6} and 9.547 × 10^{-6} $g{\cdot}s^{-1}m^{-2}$ without neutraliser. The modelling result showed agreement with the analytical result from on-site sampling. For 24 h average, the H_2S concentration was insignificant at a distance of greater than 50 m from the emission source. Similar to the previous section, the modelling result showed that, the concentration of H_2S, with neutralizer spraying, was below the odour threshold limit at 50 m. It is unlikely that the H_2S emission from the plant would lead to odour complaint or health risk to the surroundings. When Aerial Locations of Hazardous Atmospheres (ALOHA) model is used to estimate the release and dispersion of CH_4 and H_2S, Nair et. al (2019) observed that the dispersion of H_2S is not significantly sensitive to the changes of humidity and ambient temperature but sensitive to the turbulence related parameters such as wind speed.
In most of the time, the wind was coming from the north-east direction, with a moderate wind speed of 5.7 - 8.80 m/s. The wind speed surrounding the plant area was at lower speed, mostly under 3.60 m/s. The average wind speed was 2.32 m/s. A few studies have shown that microclimates condition might affect the modelling results. Moreno-Silva et al. (2020) found that wind direction significantly affected the H_2S concentration and dispersion pattern from a water reservoir, especially under critical wind conditions. Silva Neto and Freitas (2016) also found that the plume of H_2S concentration could exceed the limits of industry and lead to population's nuisance at certain weather conditions. However, based on the long-term monitoring on the wind data and H_2S concentration during dispersion, it is unlikely to lead to odour nuisance to the surroundings. Future modelling study can consider focusing on the stimulation of other specific targeted components leading to odour nuisance, such as NH_3.

4. Conclusions

This study showed the use of AESPOD for modelling the H_2S dispersion pattern from a recycled paper mill in Malaysia. The study also investigated the effect of neutraliser spraying through lab testing and explored the effect of distance and exposure time on H_2S concentration and dispersion around the area using AERMOD. It was showed that the effect of neutraliser spraying in treating H_2S decreased along with increasing distance from the emission source. At a distance of 50 m from emission source, negligible effect was found between samples treated with and without neutraliser spraying. Diving further into the effect of 1 h and 24 h average ground level concentration of H_2S, with neutraliser spraying, the model showed agreement with lab data. It is expected that the H_2S emission from the plant is insignificant and displays low health hazard potential to the nearby living community. This practice of modelling the H_2S directly is also more conclusive showing the impact of H_2S to the surrounding and would allow for easy comparison with thresholds and standards. It is recommended that future odour studies should simulate the specific component responsible for the odour.

Acknowledgments

The authors would like to acknowledge the Ministry of Education (MOE) through Fundamental Research Grant Scheme (FRGS/1/2020/TK0/UTM/02/42) provided for this study. The authors would like to acknowledge the research grants from Universiti Teknologi Malaysia (UTM) with the grant no. Q.J130000.21A2.05E75, R.J130000.7951.4S150, and R.J130000.7851.5F321, Q.J130000.2851.00L51, and Professional Development Research University (PDRU) grant no. Q.J130000.21A2.05E54.

References

Cartelle D., Vellón J.M., Rodríguez A., Valiño D., Gonzalez J.A., Casas C., Carrera-Chapela F., 2016, PrOlor: A modelling approach for environmental odour forecast, Chemical Engineering Transaction, 54, 229-234.

Dinçer F., Dinçer F.K., Sari D., Ceylan Ö., Ercan Ö., 2020, Dispersion modeling and air quality measurement to evaluate the odour impact of a wastewater treatment plant in İzmir, Atmospheric Pollution Research, 11, 2119-2125.

Greenberg M.I., Curtis J.A., Vearrier D.,2013, The perception of odor is not a surrogate marker for chemical exposure: A review of factors influencing human odor perception, Clinical Toxicology, 51, 70-76.

Lewkowska P., Cieślik B., Dymerski T., Konieczka P., Namieśnik J., 2016, Characteristics of odors emitted from municipal wastewater treatment plant and methods for their identification and deodorization techniques, Environmental Research 151, 573-586.

Lodge Jr. J.P., 1998, Methods of Air Sampling and Analysis, 3rd Edition, CRC Press, U.S.

Malaysia Pulp & Paper Chemicals Market Analysis: Plant capacity, Production, Operating Efficiency, Process, Technology, Demand & Supply, End Use, Sales Channel, Region, Competition, Trade, Market Analysis (2015-2030), <https://www.chemanalyst.com/industry-report/malaysia-pulp-paper-chemicals-market-404> accessed 30.08.2022.

Moreno-Silva C., Calvo D.C., Torres N., Ayala L., Gaitán M., González L., Rincón P., Rodríguez Susa M., 2020, Hydrogen sulphide emissions and dispersion modelling from a wastewater reservoir using flux chamber measurements and AERMOD® simulations, Atmospheric Environment 224, 117263.

Nair S.R.R., Wen J., 2019, Uncertainties in sour natural gas dispersion modelling, Chemical Engineering Transactions, 77, 355-360.

Occupational Safety and Health Administration (OSHA), Department of Labor, United States. <https://www.osha.gov/hydrogen-sulfide/hazards> accessed 30.08.2022.

Scaglia B., Orzi V., Artola A., Font X., Davoli E., Sanchez A., Adani F., 2011, Odours and volatile organic compounds emitted from municipal solid waste at different stage of decomposition and relationship with biological stability, Bioresource Technology, 102, 4638-4645.

Silva Neto O.G., Freitas C.A.L.B., 2016, Study of dispersing hydrogen sulphide (H_2S) generated from a chemical industry, Chemical Engineering Transactions 54, 235-240.

Tong X., Shen W., Chen X., 2017, Quantitative studies of ambient gases in pulp and paper mills and their degradation with photo-catalytic oxidation technology, Chapter In: Batchelor W. and Söderberg D. (Ed.), Advances in Pulp and Paper Research, Oxford 2017, FRC, Manchester, UK, 409-449.

UK Institute of Air Quality Management, 2018, IAQM Guidance on the assessment of odour for planning – version 1.1, Institute of Air Quality Management, London, <www.iaqm.co.uk/text/guidance/ odour-guidance-2014.pdf> accessed 30.08.2022.

US EPA (United States Environmental Protection Agency), 2022, Air Quality Dispersion Modeling - Preferred and Recommended Models, < https://www.epa.gov/scram/air-quality-dispersion-modeling-preferred-and-recommended-models> accessed 30.09.2022.