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EXTENDED ABSTRACT

BESTAL – Stack height determination by dispersion modelling with selected, unweighted meteorological situations

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Introduction

Waste gases from combustion and other industrial plants are discharged through stacks in order to ensure appropriate dilution of air pollutants. The Industrial Emissions Directive 2010/75/EU [1] as amended by Directive (EU) 2024/1785 [2] provides just a rough guidance on stack height when it requires this height to be "calculated in such a way as to safeguard human health and the environment." Hence, member states of the EU and states elsewhere apply their own procedures. An early international endeavour to harmonise stack height calculation was the meeting held in The Hague from 8–10 November 1967 [3].

As Briggs [4] reports, "most of the participants in this [The Hague] discussion found the general CONCAWE approach acceptable. That is, for sites with no meteorological or topographic complications, stack height can be calculated on the basis of the maximum ground concentration expected in the neutral, windy situation at the 'critical wind speed'". What Briggs refers to as the "CONCAWE approach" originates from a proposal by Holland [5] and is presented in a more elaborate version and greater detail by Brummage [6]. It is based on the combination of a Gaussian plume model with a plume rise formula and the resulting maximum ground-level concentration for a half-hour or one-hour average. This maximum concentration depends on wind speed as follows. At very light winds, plume rise is great in comparison with the true stack height, resulting in a relatively small maximum ground concentration. At the other extreme of high wind speeds, plume rise is small relative to true stack height, but maximum ground concentration is relatively small due to dilution by the wind. At an intermediate, "critical wind speed" maximum ground-level concentration is highest. When a maximum tolerable level of "critical concentration" at critical wind speed is defined, the respective minimum tolerable true stack height can be calculated. The critical wind speed is a function of momentum and buoyancy of the plume and is high for plumes with high volume flux and high temperature.

In this stack height approach the ratio of the effective stack height to the true stack height at critical wind speed is constant (effective stack height *H* being the sum of true stack height *h* plus final plume rise Δh) for a given plume rise formula. However, critical wind speed and the critical ratio H/h depend on the plume rise formula. For example, H/h at critical wind speed is 1.2 for “the ASME formula”, 2 for “the CERL formula”, and even 3 for “the CONCAWE formula”, and “there was considerable disagreement over which plume rise formula to use in this procedure” at the The Hague meeting . (cf Briggs [4])

In the German regulation on Air Quality Control (TA Luft), the above general method of stack height calculation was required in the permitting procedure from the first version of TA Luft in 1964 [7] throughout its amendments until 2002 [8]. The details of the regulatory procedure are first described in the former standard VDI 2289-1 [9] and its nomogram, the method being published by Wippermann and Klug [10] and Wippermann [11]. In 1967, at the meeting held in The Hague, “The only comprehensive procedures known to the Working Group for determining chimney heights are those due to [VDI 2289-1] and to the British Alkali Inspectorate” [6]. But by 2020, the nomogram and the related maximum tolerable concentration levels (the “S-Values” of TA Luft) had developed into a legacy element of the permitting procedure which was inconsistent with the German regulatory dispersion and plume rise model. Even to many experts in the field, the method underlying the nomogram as well as the meaning and the dimension of the S-Values (which then were given as numbers without units) had become a mystery. Therefore, a relaunch of the stack height calculation procedure was mandatory for the 2021 amendment of TA Luft [12]. The details of the new approach are given below.

Scope

The new TA Luft approach to stack height calculation ([13], chapter 2) must continue to ensure compliance with a maximum tolerable hourly mean concentration (TA Luft S-Value) in the stack-specific worst-case meteorological situation, while overcoming limitations of the old TA Luft nomogram.

- Unlike the sixty-year-old TA Luft nomogram, the new approach is consistent with the current German regulatory dispersion and plume rise model.
- The old TA Luft nomogram is only valid for moderate critical wind speeds due to limitations of the underlying Gaussian plume and plume rise models. This was tolerated on the rationale that lower and higher wind speeds only occur during 15 % of the year [9]. In contrast, the new approach is valid for all wind speed categories of the TA Luft.
- The worst-case meteorological situation of the old TA Luft nomogram is limited to the neutral, windy situation, while the stack-specific worst case meteorological situation of the new approach is selected from most stability classes. It is optimised for performance and accuracy by including stability classes very stable, stable, neutral/stable and neutral/unstable ([13], section 2.3.2.2).

- While the old TA Luft nomogram and similar traditional approaches are strictly valid only for a single stack, the new approach is applicable to multiple stacks of different heights at arbitrary distances.
- For general permitting procedures, the old nomogram is replaced by a new interactive software with a graphical user interface. In very complex settings, the new approach can also be employed with the full regulatory dispersion model, allowing for additional flexibility, e.g. accounting for complex flow fields around obstacles.

Method

The new approach is specified in the German TA Luft [12] Annex 2 No. 14 as follows:

The basis for determining the stack height according to [the new approach] are dispersion calculations [using the regulatory dispersion model], whereby the following simplifications and specifications are to be made:

a) The dispersion calculations must be performed for flat terrain.
b) The roughness length is set to 0.5 m, the displacement height to 6 times the roughness length and the anemometer height to 10 m above the displacement height.
c) The unweighted meteorological situations defined as classified dispersion situations in standard VDI 3782 Part 6 [14] are considered, excluding Klug/Manier dispersion categories [stability classes] IV and V.
d) Plume rise is taken into account by using the effective stack height (true stack height plus final plume rise) as the release height.
e) The dispersion calculation is performed for a passive, non-depositing trace gas.
f) The relative statistical standard deviation of the concentration value that determines the chimney height should not exceed 5 percent.

For each of the individual meteorological situations, the effective stack height is determined with which the specified S-Value is just met. For each individual situation, the plume rise model [of TA Luft] is then used to iteratively determine the true stack height which, when added to the corresponding final plume rise, results in the effective stack height determined above. The greatest of these true stack heights, but at least 6 m, is the true stack height […] to be used.

Implementation

The German regulatory dispersion model is a Lagrangian particle model [15] according to standard VDI 3945-3 [16]. To improve the performance of the stack height calculation tool, ground-level concentration fields for 29 effective stack heights (6 m through 905 m), and 25 combinations of stability class and wind speed category at each stack height were calculated in advance with the required statistical precision (standard deviation $\leq$ 5 %) and stored in a so-called plume library.

The German regulatory model employs a numerical three-dimensional plume rise model [17] according to standard VDI 3782-3 [18] in combination with the meteorological boundary-layer profiles of standard VDI 3783-8 [19]. This model iteratively starts from different true stack heights until the required effective stack height is met.

Two instances of the stack height calculation tool are available. BESMIN is the straightforward replacement of the old TA Luft nomogram and uses iterative reverse modelling to calculate the required true height of an individual stack. BESMAX calculates the maximum ground level concentration of all meteorological situations for any user-defined combination of stacks for comparison with the TA Luft S-Values. Both tools are included in the open-source Java package BESTAL. In addition, the reference implementation of the German regulatory dispersion model (AUSTAL) features a BESMAX option to reproduce BESMAX results.

AUSTAL and BESTAL can be downloaded as free software from https://www.umweltbundesamt.de/austal.

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