ARTICLE OVERVIEW

Ninety years ago, Carl F. Eyring published a paper\(^1\) on reverberation theory in the very first volume of JASA. In the paper, Eyring discussed a new formula for reverberation time inspired by a number of scientists of his time, among them Fokker 1924\(^2\) and Schuster and Waetzmann 1929,\(^3\) who were themselves prompted by W. C. Sabine’s introduction\(^4\) of a conceptual and quantitative framework for reverberation theory,\(^5\) specifically in the form of his famous Sabine formula for reverberation time,

\[
T = \frac{13.8}{c S a}, \quad \text{with} \quad a = \frac{\sum_{i} z_i S_i}{\sum_{i} S_i},
\]

where \(c\) is sound speed, \(V, S\) are the volume and the total interior surface area of an enclosure under consideration, \(z_a\) is the averaged absorption coefficient of the enclosure, and \(z_i\) is the individual absorption coefficient of each subsurface, \(S_i\). Eyring\(^1\) and his contemporaries\(^2,3\) studied these reverberation formulae theoretically using the image source method, focusing his attention on “dead” rooms, i.e., rooms with highly absorptive acoustic conditions. Eyring,\(^1\) along with others,\(^2,3\) confirmed Sabine’s formula of the reverberation time as accurate when the averaged absorption coefficient is low and pointed out the need to use a more general formula for enclosed spaces with highly absorptive conditions,

\[
T = 13.8 \frac{4V}{c S a \ln(1 - a)},
\]

During the fascinating historical development of reverberation theory at that time, Eyring made what was perhaps his most important contribution: experimental validation of this more general formula by investigations in a recording studio-type room, the “Sound Stage” at Bell Telephone Laboratories. The more general formula rendered Sabine’s original as a special case for “live” rooms. The Eyring\(^1\) paper became a milestone in architectural acoustics, perhaps due to his comprehensible explanation of the theory, published in English in this Journal, and his effort to provide experimental evidence demonstrating the failure of Sabine’s formula in “dead” rooms (see Figure). Since then, Eq. (2) has been known as Eyring’s formula of reverberation time. In Fig. 1, the absorption coefficients calculated using Sabine’s formula are greater than 1.0 for most frequency ranges of interest, and are nonphysical. In contrast, Eyring’s formula yields values corresponding to intrinsic physical properties. Eyring’s paper also provided reverberation times measured experimentally using a “chronographic method,”\(^6\) also documented in the same 1930 volume of JASA.

IMPACT OF THE ARTICLE

The 1930 Eyring\(^1\) article led to a series of research activities in room-acoustics reverberation theory, including further development of alternative formulae for reverberation time,\(^7\) designed variously to account for room shape and to address a number of critiques.\(^5,8\)
In recent years, Beranek has also stimulated discussions of both Sabine’s and Eyring’s formulae, applying them to the determination of audience and chair absorption in concert halls.\(^8\)

In the standardized measurement of the absorption of materials used for room-acoustic treatments, it has been well understood that chamber-based measurements of random incident absorption coefficients using Sabine’s formulae will often result in excessive, nonphysical values when the materials are highly absorptive, and great care is taken to exclude sample edge effects. In many cases, Eyring’s formula largely avoids the generation of nonphysical absorption coefficients. Even with Eyring’s formula, however, the measurement of random-incidence absorption coefficients in reverberation chambers has long been considered challenging.\(^8,10\) The issue is partially attributable to the fact that the derivations of both the formulae assumed that the absorbing power is nearly uniformly distributed over all the surfaces in the room, and that the sound field is nearly diffuse. When absorption uniformity and diffusivity or isotropy cannot be strictly guaranteed in reverberation chambers, the absorption coefficients determined by reverberation time measurements are often biased.\(^11\)

The continuing development of reverberation theory in recent years has motivated research in diffusion equation-based predictions for the accurate determination of sound energy decay in enclosures.\(^12,13\) These represent higher-order predictions because spatial variations of the reverberation energy density due to non-uniform distribution of surface absorption and variable sound source/receiver locations can be considered. In particular, the method intrinsically allows for energy flows.\(^7,13\) Recent studies involving Eyring boundary conditions have substantiated the high accuracy of the approach for the prediction of sound energy decays in reverberation fields with highly absorptive surfaces distributed non-uniformly in the room.\(^14\)

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(Published online xx September 2020)

**ACKNOWLEDGMENT**

The author thanks Dr. Cheol-Ho Jeong for his insightful discussions during the early draft of this article.

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