QUICK GUIDE

SDBDesigner

Surface Dielectric Barrier Discharge Designer

release 1.0

April 8, 2020

This software is developed for applications related with surface dielectric barrier discharge. The algorithm of this software is developed from the analytical theory of Prof. Victor Soloviev (Moscow Institute of Physics & Technology), Prof. Vladimir Krivtsov (Dorodnicyn Computing Center RAS). Validations and further corrections/improvements have been conducted based on experimental data from independent groups over the world and on the results of 2D plasma code PASSKEy parametric calculation.

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If you have any comments or suggestions for improvements, you are welcome to contact the author.

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Chapter 1

Introduction

1.1 WHAT IS SDBDESIGNER

SDBDesigner is a software developed in Python, devoted to calculate basic parameters of surface dielectric barrier discharges (or the so–called surface ionization waves). The functionalities of SDBDesigner include:

(1) Calculate the discharge and flow properties at certain condition;

(2) Calculate and draw Parametrically and automatically the discharge and fluid properties;

(3) Search the designing parameters of SDBD according to the target discharge and fluid properties.

The algorithms in this software is mainly based on the theoretical work of Prof. Victor Soloviev and Prof. Vladimir Kristov [1, 2]. The theories have been extended and validated in nanosecond pulsed discharges later.

1.2 MANUAL STRUCTURE

This manual is devoted to introduce the usage and basic algorithm of SDBDesigner.

Chapter 2 is a step-by-step tutorial. Users will learn how to use this software to calculate the discharge and fluid properties of the surface dielectric barrier discharge, and how to save and load the results.

Chapter 3 introduces the meanings of input data in the software, the value, unit and how to calculate.

Chapter 4 shows the benchmark cases.

Chapter 2

How to use

A quick guide to make use of the software.

2.1 Direct analysis

The software starts with the direct analysis page (see Figure 2.1). One has to specify the dielectric parameters, voltage parameters, gas parameters and plasma parameters.

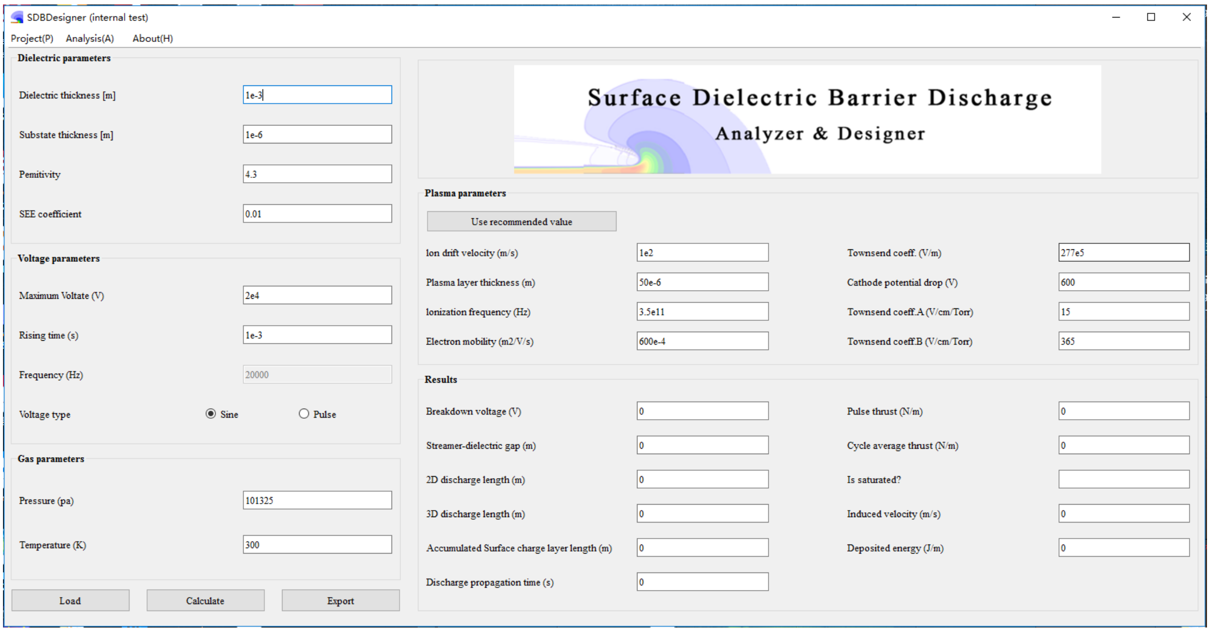

Figure 2.1: The page of "Direct analysis".

Figure 2.1 shows the default setting. Click the "Calculate" button to obtain the data in "Results" section after filling all the text boxes. A set of default values have been assigned to all the boxes. Users can replace them directly or select "Project(P)→Reset" to clean all the boxes.

The plasma parameters may be difficult for users not familiar with plasma physics, in that case it is recommended to click the "Use recommended value" button, the boxes will be filled automatically according to atmospheric conditions.

Users can click "Export" button and save the configurations and results. The saved file can be reloaded by clicking "Load" button.

The detailed explanation of the data in each text box can be found in Section 3.

2.2 Parametric analysis

To switch into parametric analysis, click on the menu "Analysis(A)→Parametric analysis". In this page you can conduct parametric sweep of 4 parameters (dielectric thickness, permittivity, maximum voltage and rising time) and see the variation trend of the discharge and fluid properties.

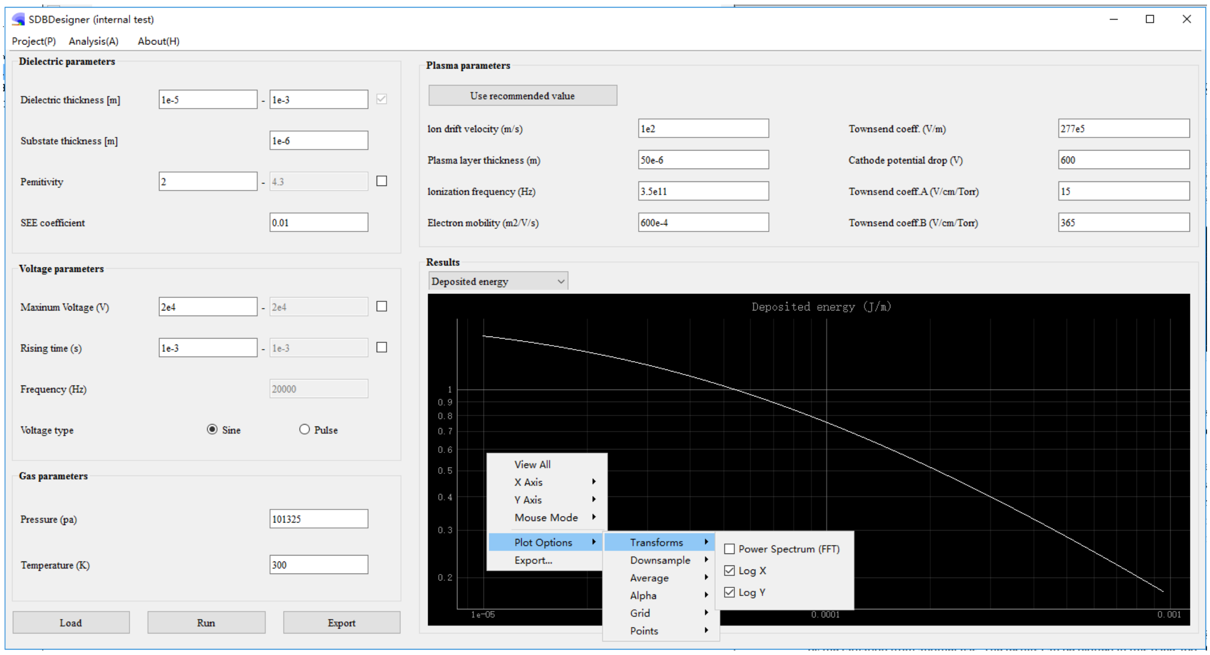

Figure 2.2: The page of "parametric analysis".

The input parameters are the same as in the page of "Direct analysis", but users can select one parameter to make parametric sweep by ticking one of the four squares (one at a time) and assign the sweep range in the enabled two boxes.

Click the "Run" button to obtain the data for "Results" section after filling all the text boxes. The results are presented as lines in the figure region on the right corner. Users can select from the list in the "Results" section to plot the variation law of different parameters. The plot style can be adjusted by right clicking on the figure and choose the corresponding options (for example, switch the x or y–axis into log or linear style, see Figure 2.2).

Click "Export" button and save the configurations and results. The saved file can be reloaded by clicking "Load" button.

2.3 Reverse design

Sometimes it is more necessary to know how to design the parameters for the SDBD to achieve certain target performances. To realize this goal, users can switch to design mode by selecting "Analysis(A)→Reverse design".

This page is similar to that of "Parametric analysis", but a new section "Design target" is added. Users have to fill in the boxes to tell the software what performance they want for their SDBD device. Users also have to fill the 2 boxes of dielectric thickness, permittivity,

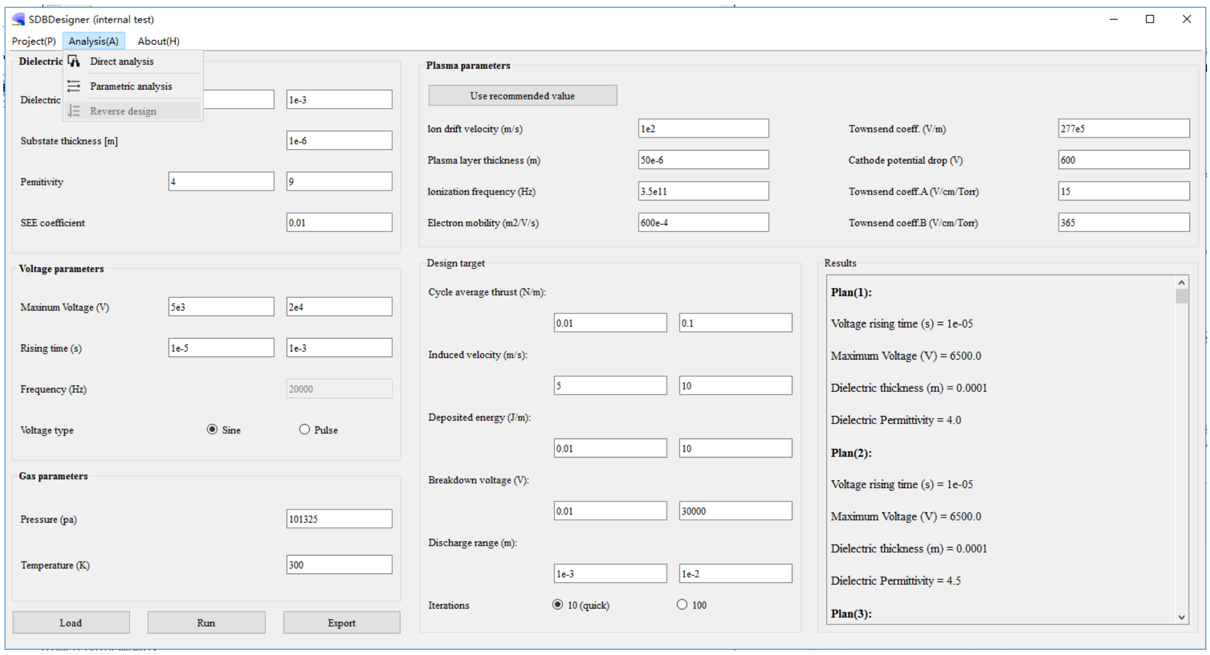

Figure 2.3: The page of "Reverse design".

maximum voltage and rising time to tell the software in which parameter range their SDBD devices can be.

It has to be noted that, in the "Design target" section, there is an "Iteration" option. Users can select "10 (quick)" to conduct a quick search (divide the searching range of the 4 parameters by 10) or select "100" to conduct a more complete search. It is strongly suggested that the users start from a large range of design parameters and target parameters and gradually reduce them.

Click "Export" button and save the configurations and results. The saved file can be reloaded by clicking "Load" button.

Chapter 3

Data explanations

This chapter explain in detail the meaning of each text box.

3.1 DIELECTRIC PARAMETERS

The dielectric parameters include dielectric thickness, substrate thickness, permittivity and secondary electron emission coefficient. The geometric scheme of the SDBD calculated by this software is drawn in Figure 3.1:

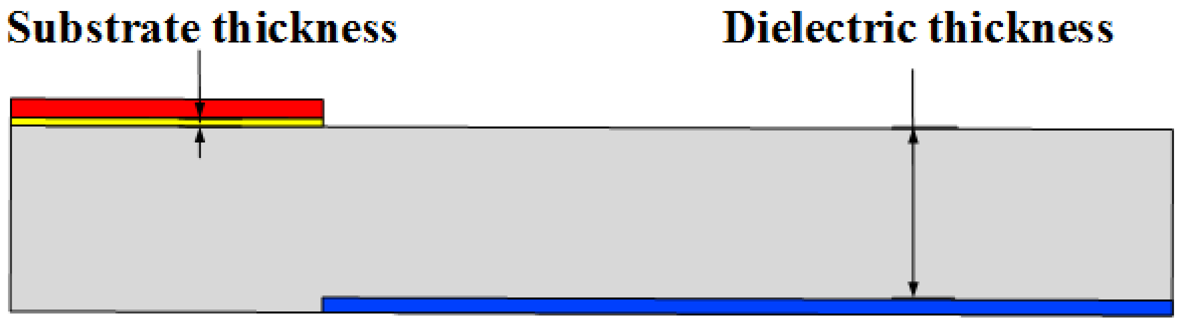

Figure 3.1: The page of “Reverse design”.

Dielectric thickness: the distance between the buried electrode and the dielectric surface.

Substrate thickness: the thickness of the material between exposed electrode and dielectric (for example, the glue).

Permittivty: the relative permitticity of the dielectric.

SEE coefficient: the secondary electron emission coefficient of the dielectric.

Note that, in the studied geometry, the x–direction distance between exposed and buried electrode should be 0. Previous studies have shown the existence of the electrode gap could lead to filaments and unsteady discharges.

3.2 VOLTAGE PARAMETERS

The voltage parameters include maximum voltage, rising time, frequency and voltage type. An description of the parameters can be found in Figure 3.2:

Maximum voltage: the peak value of the applied voltage.

Rising time: the time required for the voltage to increase from 0 to the peak value. This value may be confusing, but it helps to combine ac discharges and pulse discharges. For a sinusoidal ac voltage, the rising time is just the cycle time times 1/4.

Frequency: the repetition rate of the voltage waveform. If the **voltage type** is sinusoidal, this text box will be grey (because it can be derived from the rising time), if the voltage is a pulse, users have to specify this value.

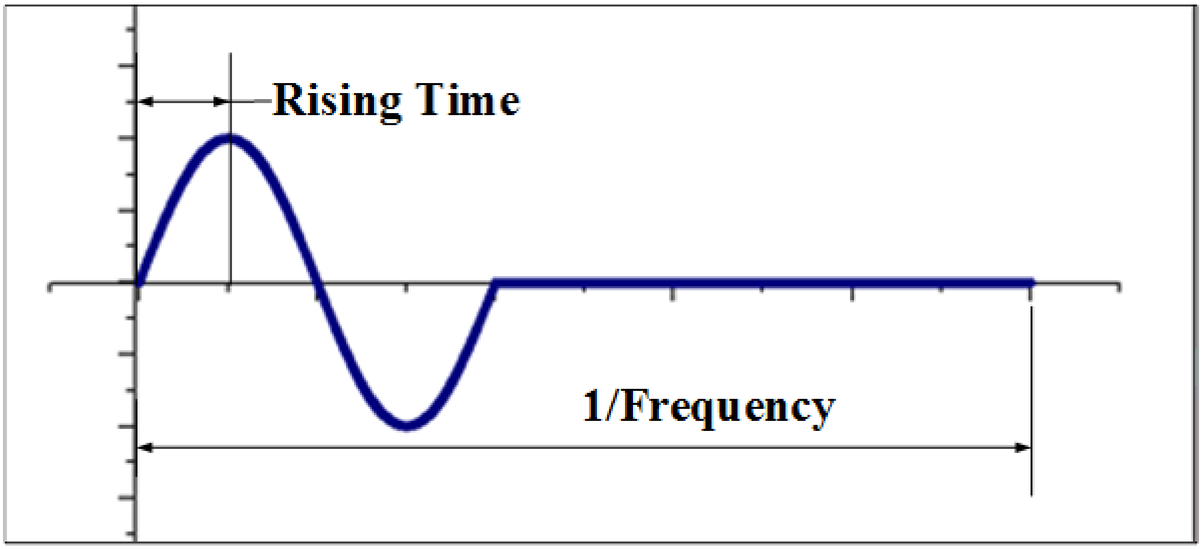

Figure 3.2: The page of “Reverse design”.

3.3 PLASMA PARAMETERS

The plasma parameters include ion drift velocity, plasma layer thickness, et al. These values are important and has to be decided according to experiments and numerical simulations. A set of default values have been embedded in the software for atmospheric condition.

Ion drift velocity: the drift velocity of ions, $V_{dr} = \mu_i E$, where μ_i is the ion mobility and can be calculated by external packages (i.e. MOBION).

Plasma layer thickness: the thickness of the surface streamer region. This value can be obtained from numerical simulations or experimental observations.

The gas ionization frequency can be estimated by $\nu_i(E) = \alpha_T(E)\mu_e E$ where α_T is the Townsend ionization coefficient and μ_e is the electron mobility. It also can be approximated by:

$$\nu_i(E) \approx \nu_{ic}(E/E_c)^2 \tag{3.1}$$

Above equation introduces two parameters, ν_{ic} and E_c:

Ionization frequency: the value of ν_{ic}. In the text box user just have to fill in the value of ν_{ic} which is a constant (3.5×10^{11}) independent of gas density[3].

Characteristic Electric field. : The value of E_c. It is proportional to gas density.

Electron mobility: the mobility of electrons, can be calculated by BOLSIG+ package.

Cathode potential drop: for SDBD in air this value is 600 V [1].

The Townsend ionization coefficient α_T can be expressed by $\alpha_T = Apexp(-Bp/E)$, where A is the **Townsend coeff.A** and B correspond to **Townsend coeff.B**.

3.4 Results

The calculated results include breakdown voltage, discharge length, et al. The formula for the values will be introduced briefly in next chapter.

Breakdown voltage: the voltage that leads to the start of the discharge.

Streamer-dielectric gap: the distance between the positive streamer body and the dielectric surface.

2D discharge length: the propagation length of the streamer under 2D approximation. This is more accurate for cases when voltage rising time is short (order of nanoseconds).

3D discharge length: the propagation length of the streamer under 3D approximation.

Accumulated surface charge layer length: the length of the surface charge layer formed after successive micro discharges in sinusoidal voltages.

Discharge propagation time: the time cost for the surface streamer to finish propagation.

Pulse thrust: the thrust produced in one pulse.

Cycle average thrust: the thrust averaged in one duty cycle.

Is saturated: for discharges driven by sinusoidal voltages, if the frequency is too high the discharge will be "saturated", the thrust can no longer increase.

Induced velocity: the induced flow velocity calculated from cycle average thrust.

Deposited energy: the deposited energy in one duty cycle.

Chapter 4

Benchmarks

The algorithms embedded in this software has been validated by a complete set of experimental and numerical results [4, 1, 2, 5, 3]. This chapter presents some external validations based on existing experimental data and numerical simulation based on PASSKEy code.

4.1 THRUST

The thrust is calculated and compared with experiments conducted by different groups from France, Netherlands, the United States and China. See Figure 4.1.

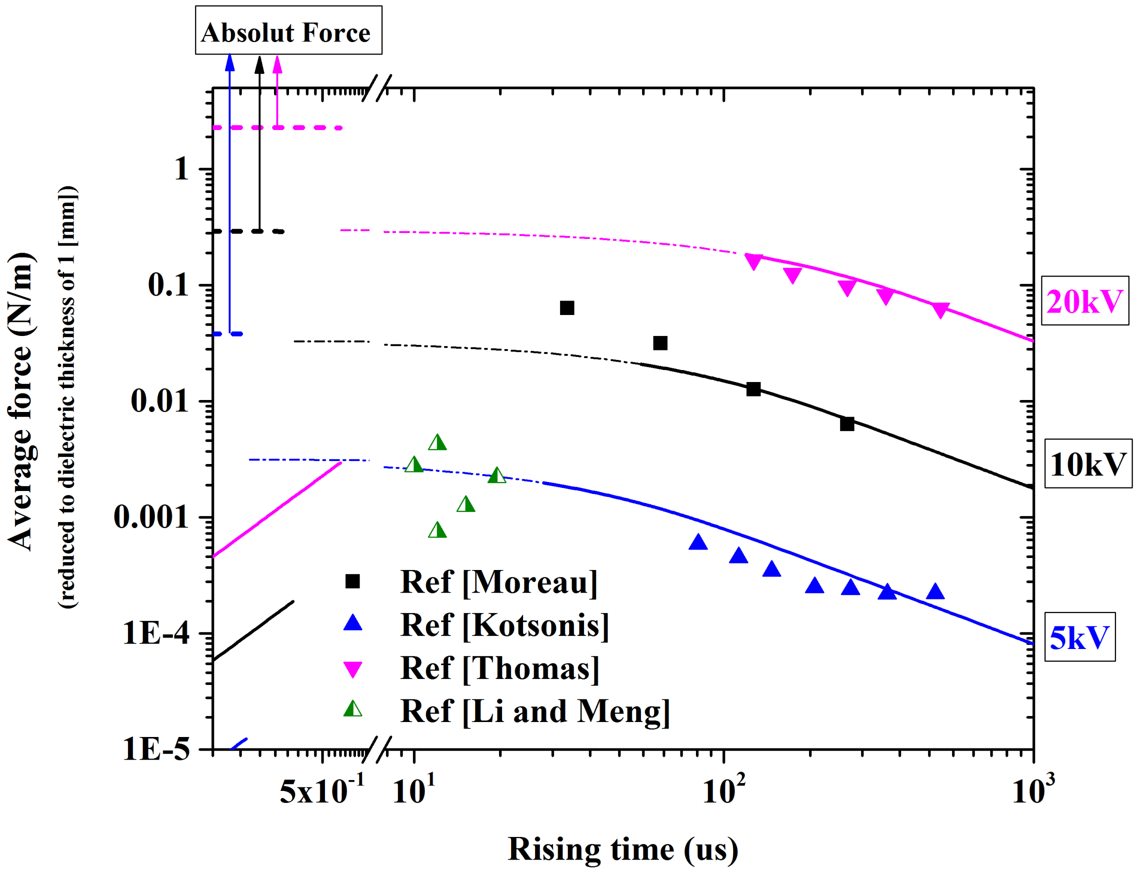

Figure 4.1: Comparison between SDBDesigner results and measurements. Solid lines are the thrust value averaged to one duty cycle, the dash–dot lines extended from solid lines are calculated results in the “saturated” region and only for reference. The dash lines are the thrust in one pulse. The experimental data are extracted from paper [6, 7, 8, 9, 10].

The calculated results are reduced to dielectric thickness of 1 mm, regardless of dielectric permittivity. Good agreement with existing independent experimental data has been achieved.

4.2 Induced velocity

The induced velocity is derived from the thrust and compared with the same experimental papers mentioned above. See Figure 4.2.

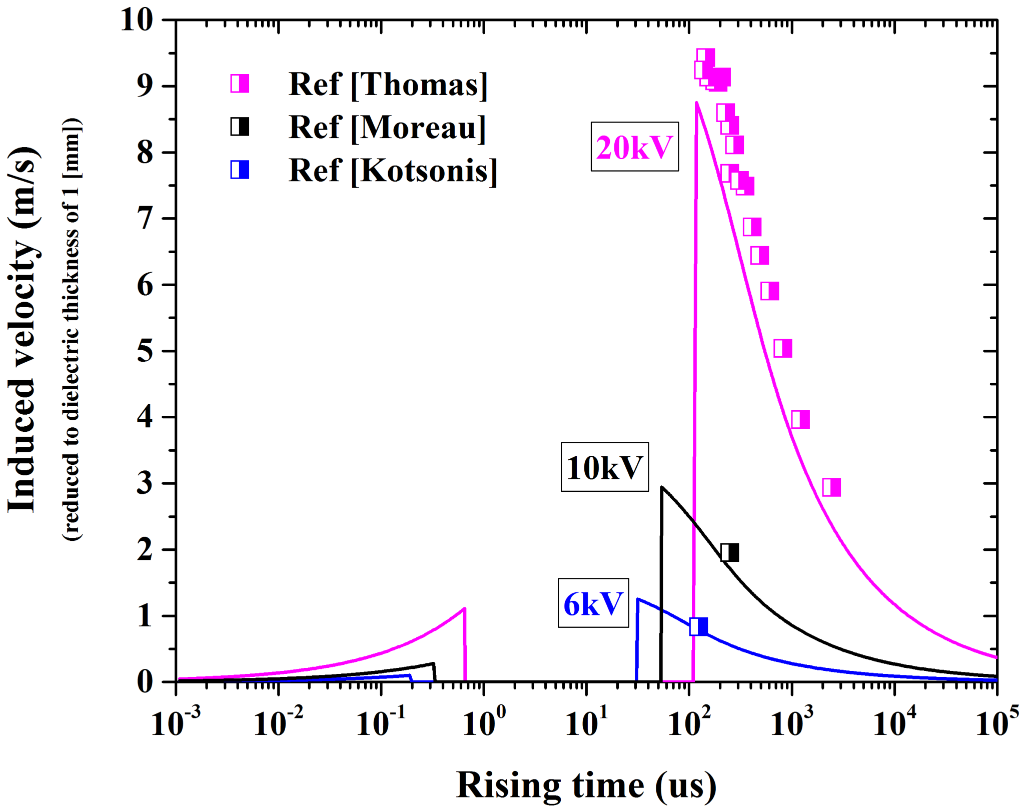

Figure 4.2: Comparison between SDBDesigner results and measurements. Solid lines are the velocity calculated from the averaged thrust. The experimental data are extracted from paper [6, 7, 8]. The results are reduced to dielectric thickness of 1 mm. To scale, one has to divide the values by the dielectric thickness.

Results calculated from SDBDesigner agree well with the measured velocity. It has to be noted that there is a gap for each velocity line. The gap corresponds to the saturated situation (when the induced velocity reaches physical maximum), the discharge is no longer uniform and the thrust will drop due to streamer contractions.

4.3 DEPOSITED ENERGY

The deposited energy per unit electrode length (span–wise) is calculated and compared with experimental measurements or validated numerical simulations in the same condition. See Figure 4.3.

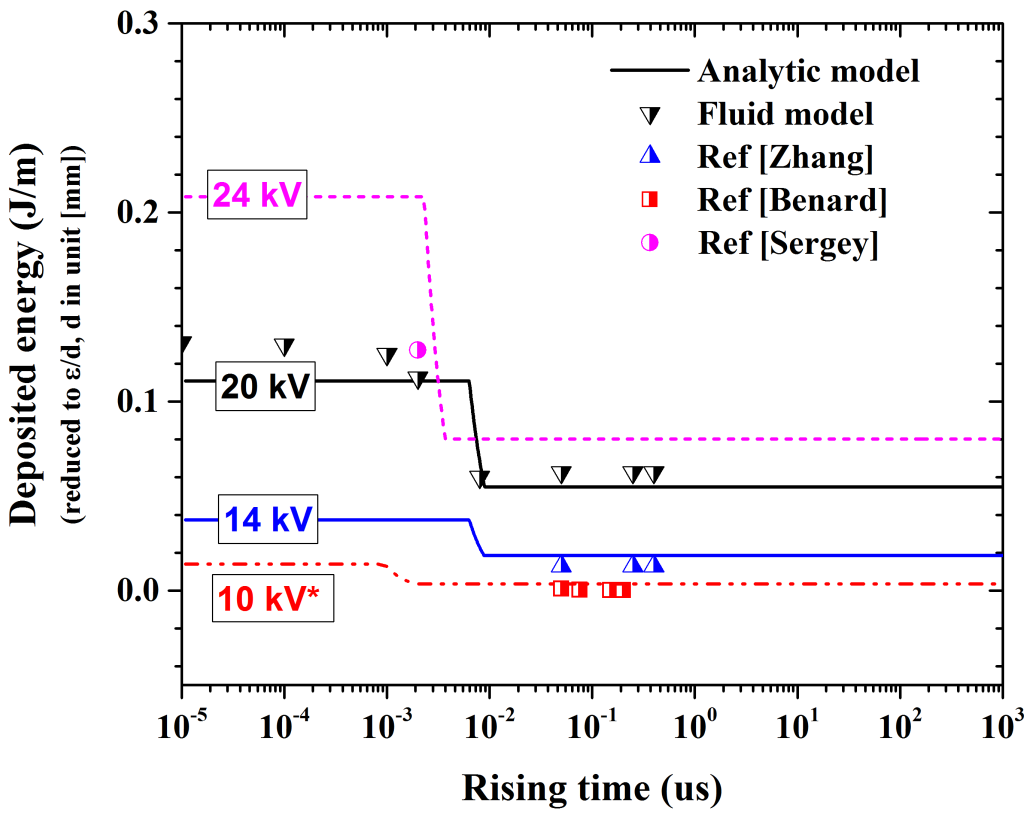

Figure 4.3: Comparison between SDBDesigner results and measurements/numerical simulations. The results are reduced by ϵ/d the permittivity and dielectric thickness. The solid, dash and dash–dot lines are obtained by SDBDesigner (different line style indicates that the ϵ/d is different). The symbols correspond to numerical simulation (by PASSKEy code), and experimental data extracted from Ref [11, 12, 13]. The 10 kV case marked with a star is special, the total deposited energy is quite small, if we plot this figure in log Y scale, the deposited energy of the 10 kV case is no longer a horizontal line.

The results are reduced by dielectric permittivity and thickness, ϵ/d. To scale, one has to multiply the values by ϵ/d. But the deposited energy is weakly dependent on ϵ, thus it is not recommended to scale directly from Figure 4.3, the best way is to conduct the calculation in SDBDesigner.

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