A program for calculation of two-phase discharge

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Introduction

The program was developed for calculation of parameters of choked/non choked discharge of two-phase gas-liquid flow. It was originally compiled for dimensioning of twin-fluid atomizers with internal mixing (effervescent atomizers). But can be used also for other applications where different parameters of pressurised two-phase gas-liquid flow to be calculated.

The discharge is calculated applying two extreme models:

- the homogeneous flow model (HFM) and
- the separated flow model (SFM).

Effect of the discharge orifice geometry: length/diameter ratio and convergence angle as well as physical properties of the dispersed/atomized liquid (viscosity and surface tension) are included into the calculation procedure.

A methodology of two-phase gas-liquid discharge as described in [1] is implemented. Also nomenclature used here follows the nomenclature used in [1]. For more information on two-phase gas-liquid flow see Corradini [2]. The program allows inputs for gas-liquid mixtures with mixing ratio covering range from pure liquid to pure gas. There is no limitation regarding fluid pressure and temperature but ideal gas low is applied here.

Description and application of the program

The program structure is simply and logically designed. The main web form is divided into two areas - input and output. User enters the input data into the main program menu (Fig. 1). The program needs basic geometrical data of the exit orifice (nozzle), operation conditions and physical properties of working fluids.

Geometrical data of the atomizer exit orifice **are given by** diameter**,** length **and** convergence angle **(180°means flat orifice) of final discharge orifice as described in [1].**

Physical properties of the fluids: **All the values are to be found in a database or measured in laboratory:** density**,** viscosity **and** liquid surface tension of the liquid, specific liquid heat capacity **(at**

constant pressure), specific gas heat capacity **at constant pressure and specific gas heat capacity at constant volume.**

Operation conditions (of the atomizer)

Ambient pressure: barometric pressure in the case of discharge into atmosphere or a pressure in a bomb when testing at elevated backpressure.

Mixing chamber overpressure: gauge pressure of the mixture measured directly in the mixing chamber. Atomising gas or liquid gauge pressure as close to the mixing chamber as possible can be also used for calculation; it is assumed that both the fluids have the same pressure which is equal to the mixture pressure for simplification.

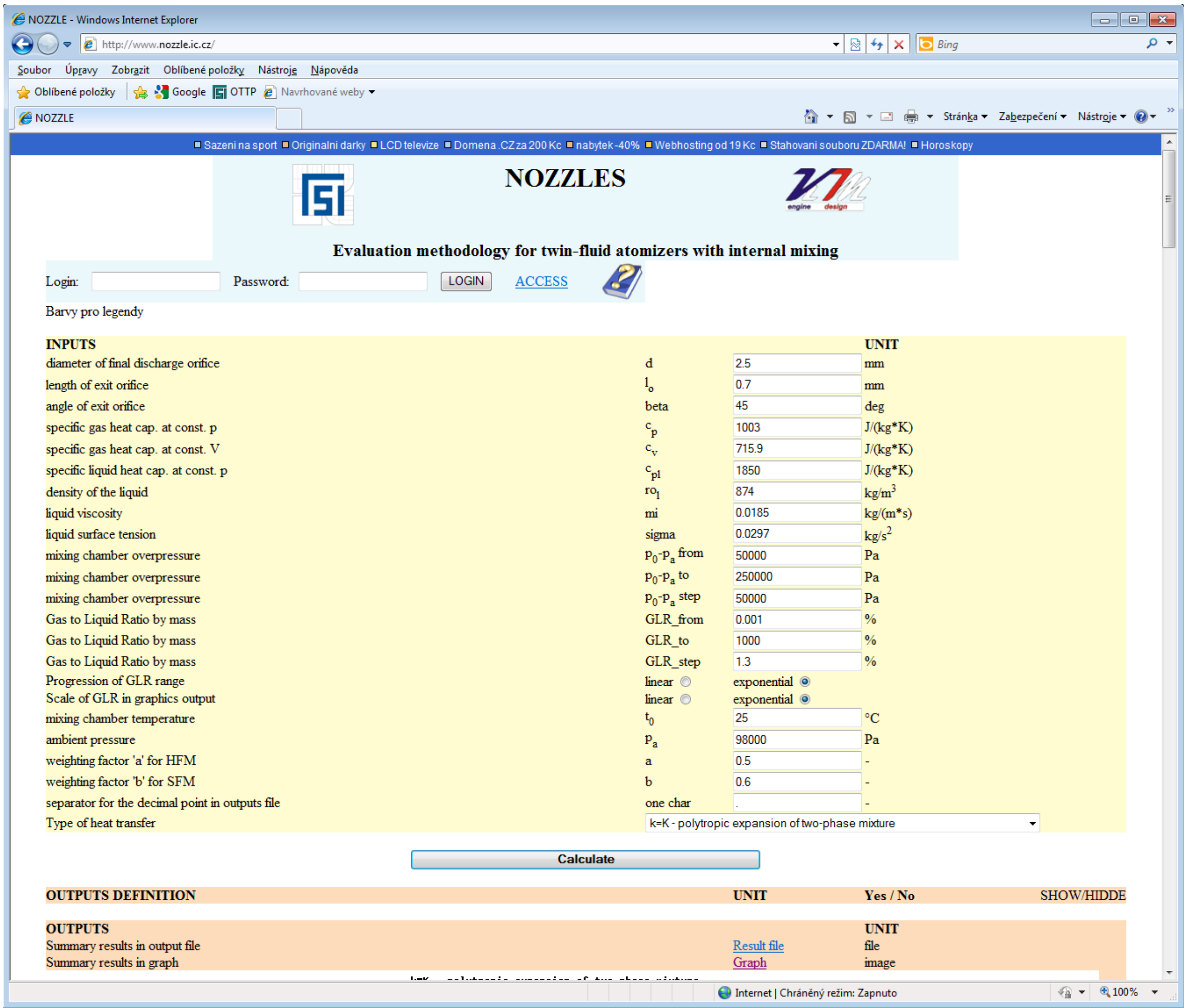


Fig. 1: Main program menu.

Mixing chamber temperature: the temperature can be directly measured in the mixing chamber or it is also possible to use gas or liquid temperature at the atomizer inlet as in the previous case.

Gas to Liquid Ratio by mass (GLR): GLR is a simple ratio between the atomising gas and the atomised liquid mass flow rates.

The calculation allows for the **Mixing chamber overpressure** and **Gas to Liquid Ratio** to be entered in a range from a minimum to a maximum value with certain step. This step (entered as "**Progression of GLR range**") can be linear or geometrical for **Gas to Liquid Ratio**. Also resulting graph can show multiple profiles for a range of **Mixing chamber overpressure** values with **Gas to Liquid Ratio** as a variable on X-axis. X-axis can have linear or logarithmic scale (entered as "**Scale of GLR in graphics**") output independently of the chosen step for **Gas to Liquid Ratio**.

All the input parameters are checked for correctness and a report appears when values out of intended range.

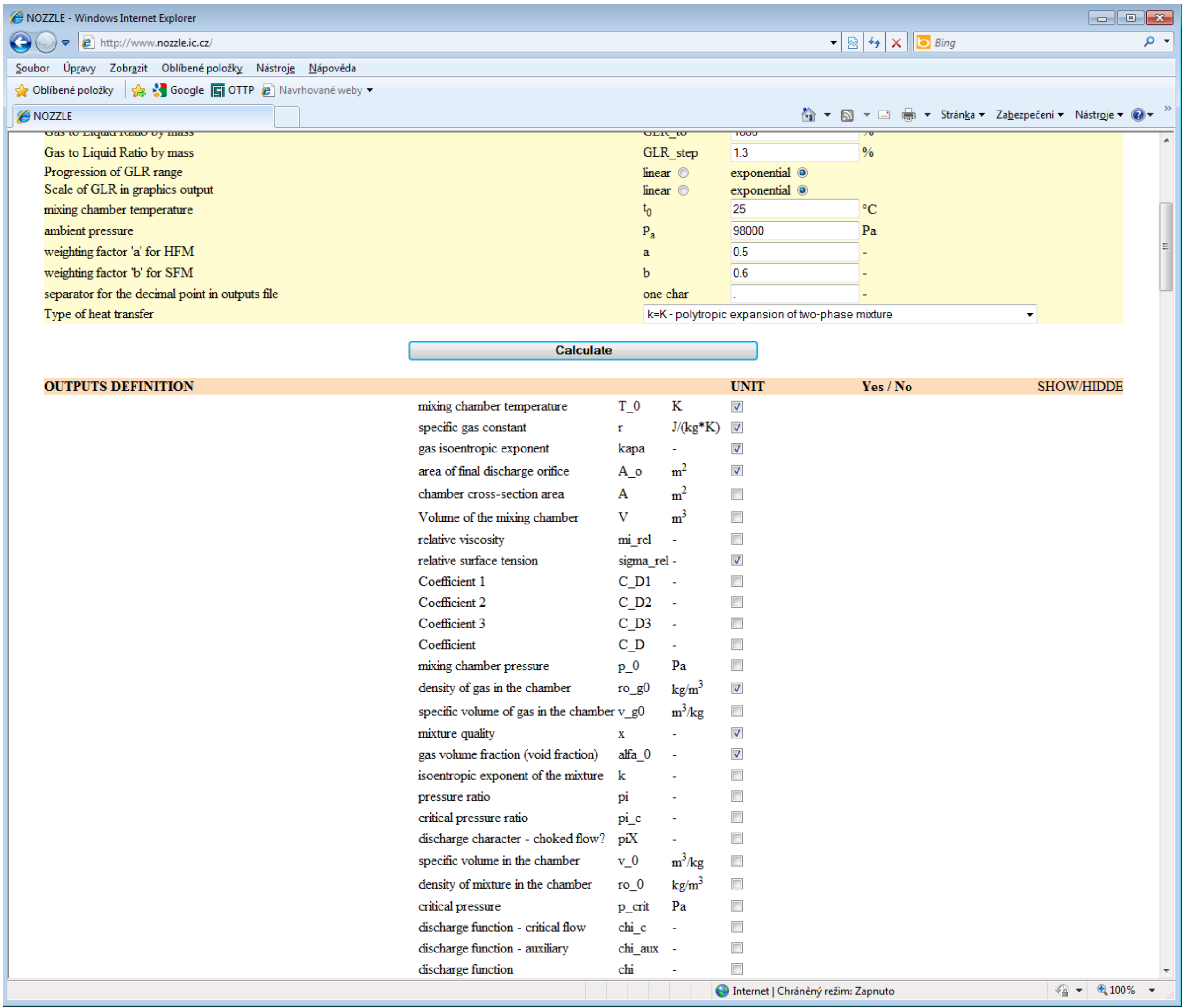


Fig. 2: Definition of the output values, expanded after click to SHOW/HIDE.

Options for the calculation

The discharge is calculated applying two extreme models (HFM and SFM). A simple linear combination of the models (see [1]) is calculated using factors „a" and „b". The factors are entered as „**weighting factor 'a' for HFM**" and „**weighting factor 'b' for SFM**".

Type of heat transfer: Calculation according both the models can be done under 1) polytropic expansion of two-phase mixture (k=K), 2) expansion with no heat transfer between phases is assumed – so called frozen flow (k=kapa) and 3) isothermal expansion of two-phase mixture (k=1).

Separator for the decimal point in outputs file (usually „.“ or „,“) is used to separate decimal numbers in the results file.

The “**Calculate**” button triggers the execution of the calculation.

OUTPUTS DEFINITION table (Fig. 2) is used to choose values to be included in the results file. This table can be opened by clicking on SHOW/HIDE button.

The results file and also a graph can be uploaded/shown using **OUTPUTS** options and is also displayed at the bottom part of the page. The graph is seen on Fig. 3 and calculated data on Fig. 4. The results can be saved into a file “**output_*hh_mm_ss*.csv**” named according actual time (hour, minute, second). The graph shows dependency of mass liquid flow rate on the **Mixing chamber overpressure** as a parameter and on the **Gas to Liquid Ratio** as variable on X-axis.

Technical note: The program searches for the critical pressure of the two-phase discharge in range from ambient pressure to ambient pressure + 1 MPa. Precision of the search is 1 Pa. It decides if the flow is choked or not and calculates gas and liquid mass flow rates, $\dot{M}_g$ and $\dot{M}_l$ respectively for given input values using corresponding equations for choked/non-choked discharge.

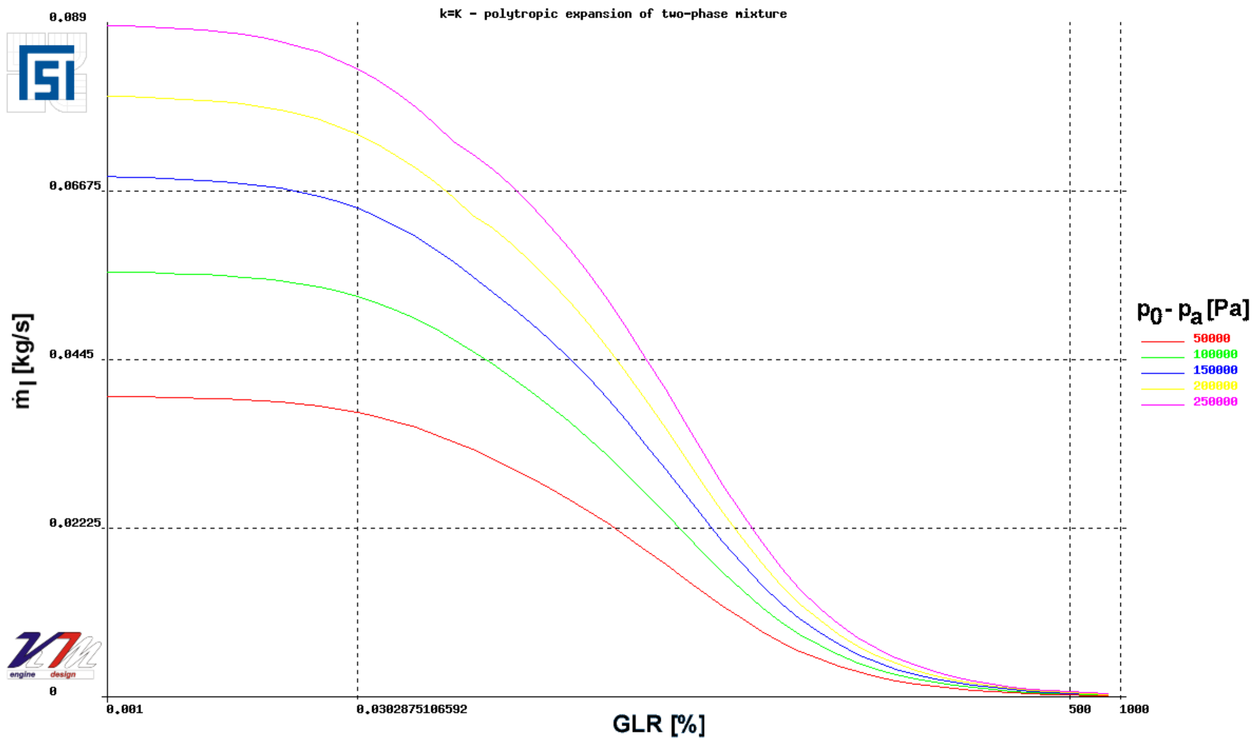


Fig. 3: Graph with results of the mass liquid flow rate.

Literature sources

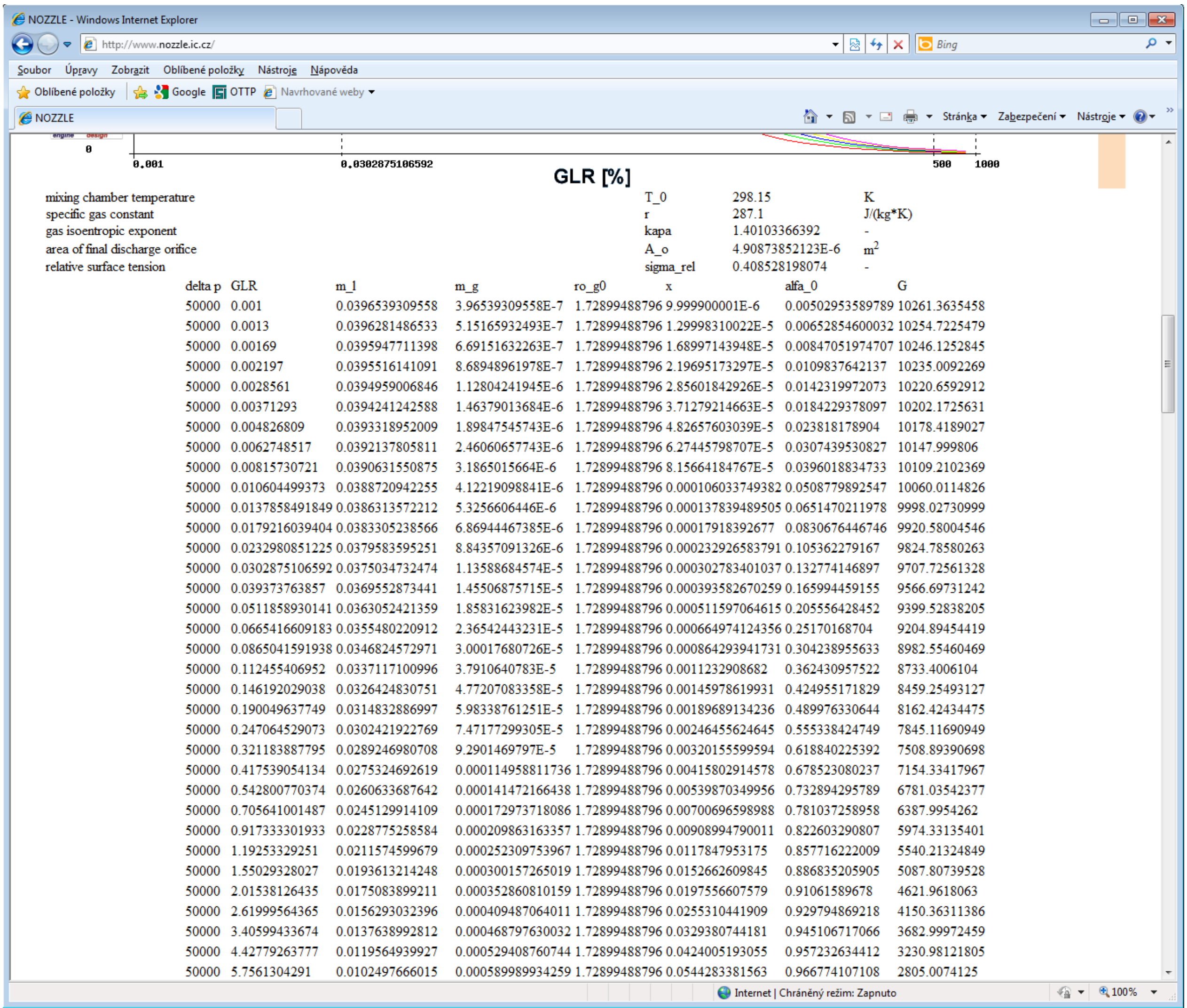
[1] Jedelsky, J., Jicha, M., Slama, J. and Otahal, J., Energy and Fuel 23:6121-6130 (2009).

[2] Corradini, M. L. Fundamentals of Multiphase Flow. Available at: WWW. http://wins.engr.wisc.edu/teaching/mpfBook/, (Accessed July 2007).

Technical requirements

The program is a web based application (not installed on the local hard drive) limited by two main parameters – the speed of user's internet connection and the quality of the web server on which the application is running. Both these parameters influence the operation success. Web based applications generally use procedures of the calculation in limited time. This time limit for execution of the program is 15 seconds. The most time-consuming task is the calculation procedure. Please be careful when enter data for **Mixing chamber overpressure** and **Gas to Liquid Ratio.** Too small "step" in relation to the data limits results in large number of calculations which lasts for long and also produces overcrowded graph.

Another user's PC requirements aren't currently important – PC Pentium I and higher, 64 MB RAM, VGA and operating system WIN 95 or higher. The application is designed for Internet Explorer 7.0 or higher and successfully tested on other web browsers – Opera, Mozilla Firefox, Opera, Google Chrome and Safari.



mixing chamber temperature	T_0	298.15	K
specific gas constant	r	287.1	J/(kg*K)
gas isoentropic exponent	kapa	1.40103366392	-
area of final discharge orifice	A_o	4.90873852123E-6	m^2
relative surface tension	sigma_rel	0.408528198074	-

delta p	GLR	m_l	m_g	ro_g0	x	alfa_0	G
50000	0.001	0.0396539309558	3.96539309558E-7	1.72899488796	9.999900001E-6	0.00502953589789	10261.3635458
50000	0.0013	0.0396281486533	5.15165932493E-7	1.72899488796	1.29998310022E-5	0.00652854600032	10254.7225479
50000	0.00169	0.0395947711398	6.69151632263E-7	1.72899488796	1.68997143948E-5	0.00847051974707	10246.1252845
50000	0.002197	0.0395516141091	8.68948961978E-7	1.72899488796	2.19695173297E-5	0.0109837642137	10235.0092269
50000	0.0028561	0.0394959006846	1.12804241945E-6	1.72899488796	2.85601842926E-5	0.0142319972073	10220.6592912
50000	0.00371293	0.0394241242588	1.46379013684E-6	1.72899488796	3.71279214663E-5	0.0184229378097	10202.1725631
50000	0.004826809	0.0393318952009	1.89847545743E-6	1.72899488796	4.82657603039E-5	0.023818178904	10178.4189027
50000	0.0062748517	0.0392137805811	2.46060657743E-6	1.72899488796	6.27445798707E-5	0.0307439530827	10147.999806
50000	0.00815730721	0.0390631550875	3.1865015664E-6	1.72899488796	8.15664184767E-5	0.0396018834733	10109.2102369
50000	0.010604499373	0.0388720942255	4.12219098841E-6	1.72899488796	0.000106033749382	0.0508779892547	10060.0114826
50000	0.0137858491849	0.0386313572212	5.3256606446E-6	1.72899488796	0.000137839489505	0.0651470211978	9998.02730999
50000	0.0179216039404	0.0383305238566	6.86944467385E-6	1.72899488796	0.00017918392677	0.0830676446746	9920.58004546
50000	0.0232980851225	0.0379583595251	8.84357091326E-6	1.72899488796	0.000232926583791	0.105362279167	9824.78580263
50000	0.0302875106592	0.0375034732474	1.13588684574E-5	1.72899488796	0.000302783401037	0.132774146897	9707.72561328
50000	0.039373763857	0.0369552873441	1.45506875715E-5	1.72899488796	0.000393582670259	0.165994459155	9566.69731242
50000	0.0511858930141	0.0363052421359	1.85831623982E-5	1.72899488796	0.000511597064615	0.205556428452	9399.52838205
50000	0.0665416609183	0.0355480220912	2.36542443231E-5	1.72899488796	0.000664974124356	0.2517016870 4	9204.89454419
50000	0.0865041591938	0.0346824572971	3.00017680726E-5	1.72899488796	0.000864293941731	0.304238955633	8982.55460469
50000	0.112455406952	0.0337117100996	3.7910640783E-5	1.72899488796	0.0011232908682	0.362430957522	8733.4006104
50000	0.146192029038	0.0326424830751	4.77207083358E-5	1.72899488796	0.00145978619931	0.424955171829	8459.25493127
50000	0.190049637749	0.0314832886997	5.98338761251E-5	1.72899488796	0.00189689134236	0.489976330644	8162.42434475
50000	0.247064529073	0.0302421922769	7.47177299305E-5	1.72899488796	0.0024645562464 5	0.555338424749	7845.11690949
50000	0.321183887795	0.0289246980708	9.2901469797E-5	1.72899488796	0.00320155599594	0.618840225392	7508.89390698
50000	0.417539054134	0.0275324692619	0.000114958811736	1.72899488796	0.00415802914578	0.678523080237	7154.33417967
50000	0.542800770374	0.0260633687642	0.000141472166438	1.72899488796	0.00539870349956	0.732894295789	6781.03542377
50000	0.705641001487	0.0245129914109	0.000172973718086	1.72899488796	0.00700696598988	0.781037258958	6387.9954262
50000	0.917333301933	0.0228775258584	0.000209863163357	1.72899488796	0.00908994790011	0.822603290807	5974.33135401
50000	1.19253329251	0.0211574599679	0.000252309753967	1.72899488796	0.0117847953175	0.857716222009	5540.21324849
50000	1.55029328027	0.0193613214248	0.000300157265019	1.72899488796	0.0152662609845	0.886835205905	5087.80739528
50000	2.01538126435	0.0175083899211	0.000352860810159	1.72899488796	0.0197556607579	0.91061589678	4621.9618063
50000	2.61999564365	0.0156293032396	0.000409487064011	1.72899488796	0.0255310441909	0.929794869218	4150.36311386
50000	3.40599433674	0.0137638992812	0.000468797630032	1.72899488796	0.0329380744181	0.945106717066	3682.99972459
50000	4.42779263777	0.0119564939927	0.000529408760744	1.72899488796	0.0424005193055	0.957232634412	3230.98121805
50000	5.7561304291	0.0102497666015	0.000589989934259	1.72899488796	0.0544283381563	0.966774107108	2805.0074125

Fig. 4: Table with results for values chosen.

Licence agreement and usage of the program

Usage of the program by other subject is possible after a licence agreement and the program is for non-commercial usage only. The program can be run from a web http://www.nozzle.ic.cz/. Three attempts of calculation after first onloading web page are free for usage. For further usage it is necessary to have access rights – login and password for the unlimited usage of the program. The official international licensee is Brno University of Technology.

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