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THE DETERMINATION OF EXIT PARAMETERS OF MEDIA FLOWING THROUGH NARROW CHANNELS OF BOTTOM TUYERES OF HIGH-TEMPERATURE UNITS

URČENÍ VÝSTUPNÍCH PARAMETRŮ MÉDIÍ PROUDÍCÍCH ÚZKÝMI KANÁLKY PŮDNÍCH DMYŠEN VYSOKOTEPLOTNÍCH AGREGÁTŮ

Abstract

For blowing gaseous technological media into the melt below the level thereof, special designs of tuyeres are used in high-temperature units. The structural design of the majority of these tuyeres considers one or more channels composed of steel tubes or formed directly in the basic refractory material of the tuyere. From the point of view of structural design of these tuyeres, it is very important to know the dependence of exit parameters of blown media on the design parameters of the tuyere; the parameters determined with one channel being taken as a basis. The contribution contains a description and chosen results of two-dimensional mathematical modelling of gaseous medium flow through a narrow channel with given dimensional parameters.

Abstrakt

Pro dmýchání plynných technologických médií pod hladinu taveniny se ve vysokoteplotních agregátech využívají speciální konstrukce dmyšen. Většina těchto dmyšen je konstrukčně řešena tak, že se jedná o jeden nebo více kanálků tvořených ocelovými trubicemi nebo jsou tyto kanálky vytvořeny přímo v základním žáruvzdorném materiálu dmyšny. Z hlediska konstrukčního návrhu těchto dmyšen je velmi důležité znát závislosti výstupních parametrů dmýchaných médií na konstrukčních parametrech dmyšny přičemž vycházíme z parametrů určených u jednoho kanálku. Příspěvek obsahuje popis a vybrané výsledky dvoudimenzionálního matematického modelování proudění plynného média úzkým kanálkem s danými rozměrovými parametry.

1 INTRODUCTION

Special designs of tuyeres are used in high-temperature units for blowing gaseous technological media into the melt below the melt level. These special tuyeres are formed by one or more channels made of steel tubes or directly in the basic refractory material.

For the experiment, we chose one of channels forming a so-called MTP (multiple tuyere plug) (Figure 1) tuyere. These tuyeres are usually composed of several tubes of internal diameter of 0.5 to 6mm. The tubes are embeded in a refractory material. The spacing of individual tubes moves in the range from 12 to 40mm.

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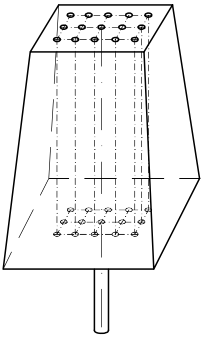


Figure 1 - Diagram of MTP tuyere

2 TASK AND INITIAL DATA

For the calculation (mathematical modelling), it is necessary to acquire as accurate as possible data concerning both the entry of the gaseous medium and the geometric dimensions of the channel. Here, so-called boundary conditions of calculation are referred to. The more accurate the determination of boundary conditions is, the more accurate results may be expected. A diagram of one flow channel and the whole computational area is presented in Figure 2.

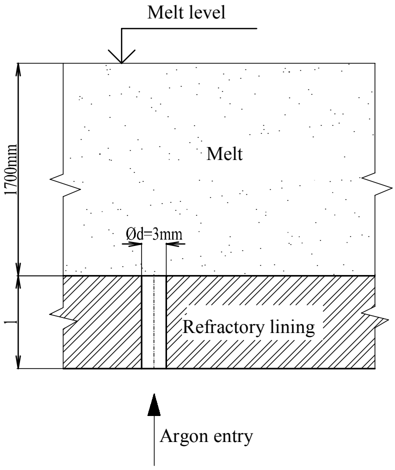


Figure 2 - Diagram of one flow channel and the whole computational area

The goal of numerical solving of argon flow through a channel of the diameter **d** and the length **l** was to determine the distribution of basic state quantities **v**, **p**, **ρ** and **T** (velocity, pressure, density and temperature) along the length and in the exit (transversal) cross-section of the channel.

☐ Other set parameters:

Melt density	ρ_{tav}=7000 kg.m^{-3}
Melt temperature	T_{tav}=1973 K

☐ Definition of operating conditions:

Nominal volume flow rate	Qvp=10.5263 lAr.min-1 = 1.75439.10-4 m3.s-1
Nominal mass flow rate	Qmp=3.1298.10-4 kg.s-1
Ar pressure at entry into the channel at nominal flow rate	p=1 MPa

☐ Physical properties of argon (Ar):

	Designation	Units	Range	Value, dependence
Molecular weight	M_{Ar}	$kg.kmol^{-1}$		39.95
Density in normal state	ρ_N	$kg.m^{-3}$		1.784
Specific heat capacity	c_p	$J.kg^{-1}K^{-1}$	T=<273-2000>[K]	$c_p = 2.74E\text{-}7T^3 - 3.67E\text{-}6T^2 + 7.07E\text{-}06T + 520.3$
Thermal conductivity	λ	$W.m^{-1}K^{-1}$	T=<273-2000>[K]	$\lambda = 5.53E\text{-}12T^3 - 2.18E\text{-}8T^2 + 5.54E\text{-}5T + 0.0027$
Dynamic viscosity	η	Pa.s	T=<273-2000>[K]	$\eta = -1.28E\text{-}11T^2 + 6.34E\text{-}08T + 4.39E\text{-}6$

Table 1 – Physical properties of argon depending upon temperature

Channels of the lengths of 750 and 1330mm and of the same flow diameter of 3mm were tested. The temperature of argon at the entry into the channel **T** was 293K for both the computational lengths and moreover the temperature of 350K for the computational length of 1330mm. The channel was produced directly in the refractory lining.

For every computational case, a calculation was executed in two phases. In the first phase, such minimum mass flow rate of argon (Q_{m-min}) was determined that the static pressure of it in the exit cross-section of the channel was equal to the ferrostatic pressure in the same point on given computational conditions. In the second phase, the calculation for conditions (Q_{mp}) corresponding to the defined operating state was performed.

3 CALCULATION RESULTS

For every computational case, results of mathematical modelling are clearly arranged in the following tables 2-7.

Results for l=750 mm; T=293 K

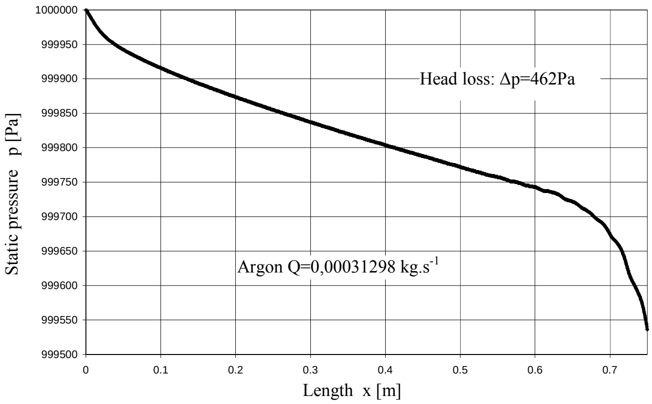
	p [Pa]	v_s [$m.s^{-1}$]	T_s [K]	ρ_s [$kg.m^{-3}$]
Q_{m-min}=0.000078 [$kg.s^{-1}$]	218212	2.76	293	3.54
Q_{mp}=0.00031298 [$kg.s^{-1}$]	1000000	2.76	293	16.36

Table 2 – Comparison of mean values at the entry

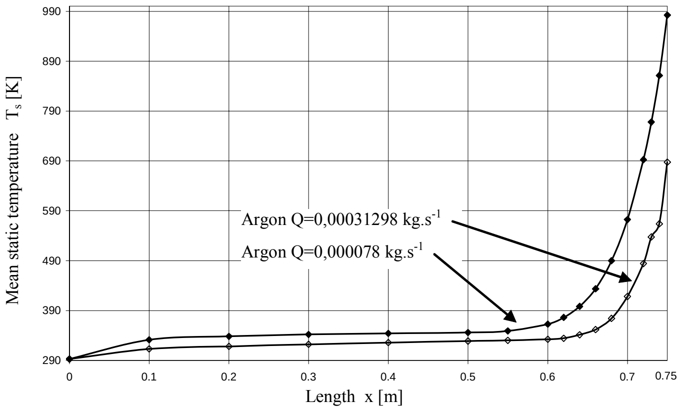
	p [Pa]	v_s [$m.s^{-1}$]	T_s [K]	ρ_s [$kg.m^{-3}$]
Q_{m-min}=0.000078 [$kg.s^{-1}$]	217740	11.12	982.11	1.29
Q_{mp}=0.00031298 [$kg.s^{-1}$]	999536	6.19	687.36	9.26

Table 3 – Comparison of mean values at the exit

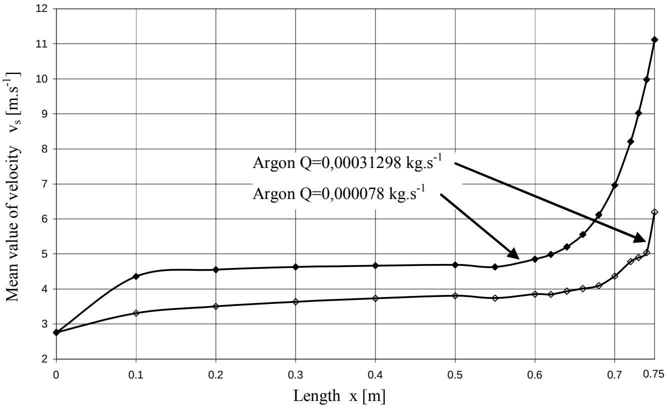
The course of changes in the mean values of observed state quantities of argon along the length of the channel is documented by graphs given below, Graphs 1-7. Trends in the changes are practically similar in all computational cases, and for this reason, merely the graphs that relate to the first computational case are presented. In the graphs, "*distance x*" means the distance in the longitudinal direction (in the direction of channel length) and "*distance y*" in the radial direction.



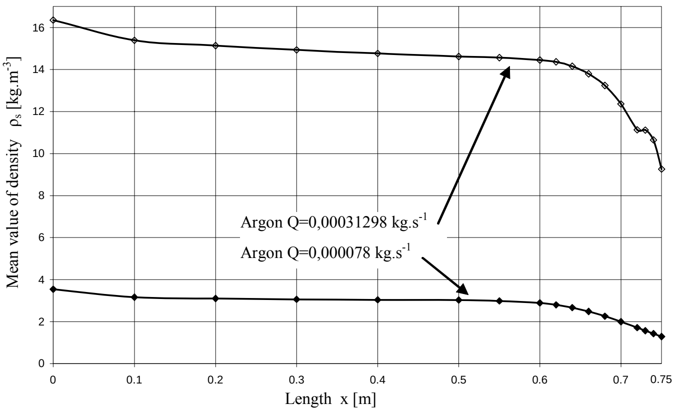
Graph 1 – Course of static pressure along the length of the nozzle (operating state)



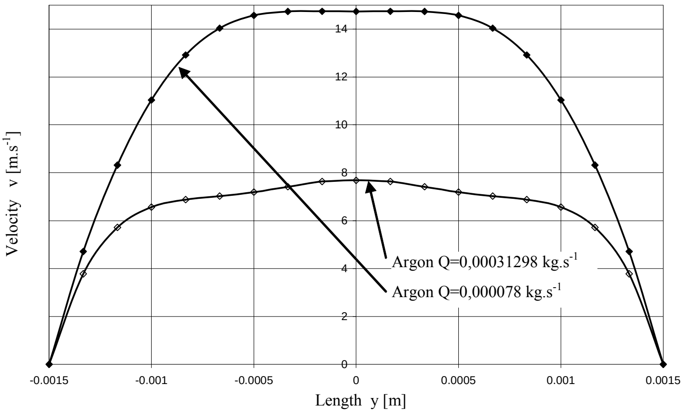
Graph 2 – Course of mean static temperature along the length of the nozzle



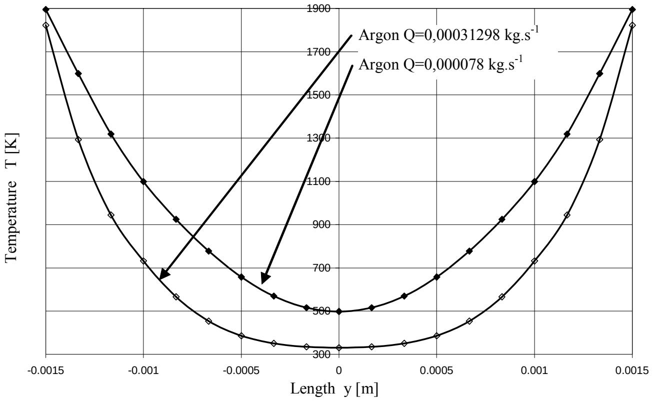
Graph 3 – Course of the mean value of velocity along the length of the nozzle



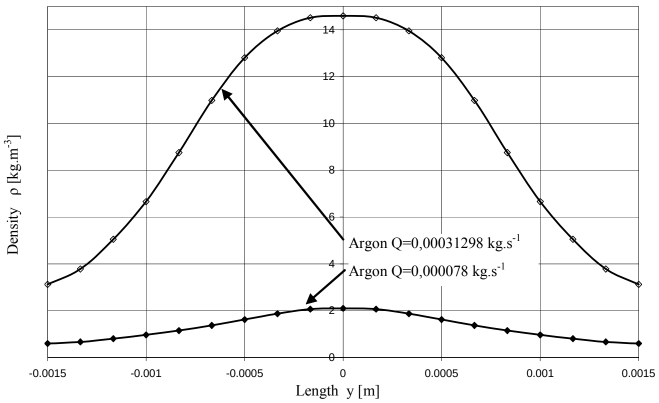
Graph 4 – Course of the mean value of density along the length of the nozzle



Graph 5 – Course of velocity in the exit cross-section



Graph 6 – Course of temperature in the exit cross-section



Graph 7 – Course of density in the exit cross-section

Results for l=750 mm; T=350 K

	p [Pa]	v_s [m.s^{-1}]	T_s [K]	ρ_s [kg.m^{-3}]
Q_{m-min}=0.000105 [kg.s^{-1}]	218382	4.435	349.98	2.998
Q_{mp}=0.00031298 [kg.s^{-1}]	1000000	2.887	349.99	13.727

Table 4 – Comparison of mean values at the entry

	p [Pa]	v_s [m.s^{-1}]	T_s [K]	ρ_s [kg.m^{-3}]
Q_{m-min}=0.000105 [kg.s^{-1}]	217740	13.224	906.49	1.468
Q_{mp}=0.00031298 [kg.s^{-1}]	999599	5.258	634.09	10.153

Table 5 – Comparison of mean values at the exit

Results for l=1330 mm; T=350 K

	p [Pa]	v_s [m.s^{-1}]	T_s [K]	ρ_s [kg.m^{-3}]
Q_{m-min}=0.000255 [kg.s^{-1}]	220282	10.67	350	3.03
Q_{mp}=0.00031298 [kg.s^{-1}]	1000000	2.89	350	13.73

Table 6 – Comparison of mean values at the entry

	p [Pa]	v_s [m.s^{-1}]	T_s [K]	ρ_s [kg.m^{-3}]
Q_{m-min}=0.000255 [kg.s^{-1}]	217742	25.86	778.03	1.81
Q_{mp}=0.00031298 [kg.s^{-1}]	999410	5.54	657.48	9.82

Table 7 – Comparison of mean values at the exit

4 EVALUATION OF RESULTS

The final evaluation of results is again carried out in a form of following tables 8-9, where changes in individual observed state quantities between the entry and the exit cross-section of the channel for the minimum amount of mass $Q_{m\text{-}min}$ and for the operating state Q_{mp} are clear. The plus sign (+) means an increase in the given value and the minus sign (–) a decrease in it.

Computational variant	Δp [Pa]	Δv [m.s^{-1}]	ΔT [K]	Δρ [kg.m^{-3}]	$Q_{m\text{-}min}$ [kg.s^{-1}]
l=750mm ; T=293K	-472	+8.36	+689.11	-2.25	0.000078
l=750mm ; T=350K	-642	+8.789	+556.51	-1.53	0.000105
l=1330mm; T=350K	-2540	+15.19	+428.03	-1.22	0.000255

Table 8 – Comparison of changes in state quantities between the entry and the exit cross-section of the channel for $Q_{m\text{-}min}$

Computational variant	Δp [Pa]	Δv [m.s^{-1}]	ΔT [K]	Δρ [kg.m^{-3}]	Q_{mp} [kg.s^{-1}]
l=750mm ; T=293K	-464	+3.43	+394.36	-7.1	0.00031298
l=750mm ; T=350K	-401	+2.371	+284.1	-3.574	0.00031298
l=1330mm; T=350K	-590	+2.65	+307.48	-3.91	0.00031298

Table 9 – Comparison of changes in state quantities between the entry and the exit cross-section of the channel for Q_{mp}

5 CONCLUSION

By the determination of $Q_{m\text{-}min}$, a limit was determined below which the mass flow rate of argon through one channel should not theoretically drop for the given length of the channel, the entry temperature of argon and the static pressure in the exit cross-section.

If we evaluate changes in the state quantities on given computational conditions in the operating state, which interests us most, the following can be stated:

a) With an increase in the entry temperature of argon (from 293K to 350K) at the constant length of the channel (750mm), a decrease in pressure loss, a change in density, an increment in temperature and velocity in the exit cross-section occur,

b) With an increase in the length of the channel at the constant entry temperature of argon, changes in all observed state quantities grow.

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