Mass Flows of Gases and Vapours through Nozzles

According to the Law of Continuity

$$\dot{M} = a \cdot w \cdot \rho$$

$\dot{M}$	=	Mass flow
a	=	Flow cross section
w	=	Velocity
ρ	=	Density of flowing medium
p_1	=	Pressure before the nozzle
ϑ_1	=	Temperature before the nozzle
c	=	Specific Heat capacity
φ	=	Coefficient of loss

The aforementioned equation is valid for any point in a nozzle, when the values for a, w and ρ, present at this point, are filled in.

The mass flow through a nozzle is determined by the narrowest cross section of the nozzle.

With the diminishing cross section, the velocity w = 0 at the condition p_1, ϑ_1 and ρ_1, increases up the narrowest point of the nozzle. At critical or over-critical pressure drops, sonic velocity is reached at this point. Supercritical pressure drops followed by a diverging nozzle section (LAVAL NOZZLE) further increase the velocity.

This critical pressure ratio is only dependent on the ratio of the specific heat capacities

$c_p/c_v = \kappa$ and therewith constant for a particular gas:

$$p_{crit.}/p_1 = \left(\frac{2}{\kappa+1}\right)^{\frac{\kappa}{\kappa-1}}$$

The mass flow through a nozzle whose inlet pressure p1 is constant, first increases with decreasing pressure downstream of the nozzle. The mass flow reaches its maxium at the critical pressure ratio and from then on remains constant.

For the calculation of mass flows through a nozzle, two cases have to be considered:

a) critical or supercritical pressure drops

b) subcritical pressure drops

In most cases steam jet pumps are operated with nozzles operating at supercritical pressure drops. Only these nozzles will be considered in the following.

Assuming an adiabatic expansion in the nozzle, the mass flow is calculated as fol-

$$\dot{M} = \varphi \cdot \Psi_{crit.} \cdot a \cdot \sqrt{2p_1 \cdot \rho_1}$$

lows:

$$\Psi_{crit.} = \left(\frac{2}{\kappa+1}\right)^{\frac{1}{\kappa-1}} \sqrt{\frac{\kappa}{\kappa+1}}$$

with

Thus, the mass flow only depends on the condition of the gas upstream of the nozzle and its properties. The coefficients of loss of well finished nozzles are today so well known that for the purpose of calculating the mass flow, the motive nozzles of jet pumps supply far more accurate values than any other form of throughput measuring.

Therefore motive nozzles can be directly used for the exact calculation of the motive medium mass flow rate.

For water vapour (steam) the following values are used:
κ= 1.3.This value is valid for superheated steam and for saturated steam as in spite of the expansion leading in the wet steam range, the steam remains dry due to delayed condensation.

At κ= 1.3 the critical pressure drop results with
$p_1/p_{crit.}$= 1.83 $\psi_{crit.}$= 0.473
The diagram was prepared with these values and with the equation for the mass flow.

Two examples are shown:

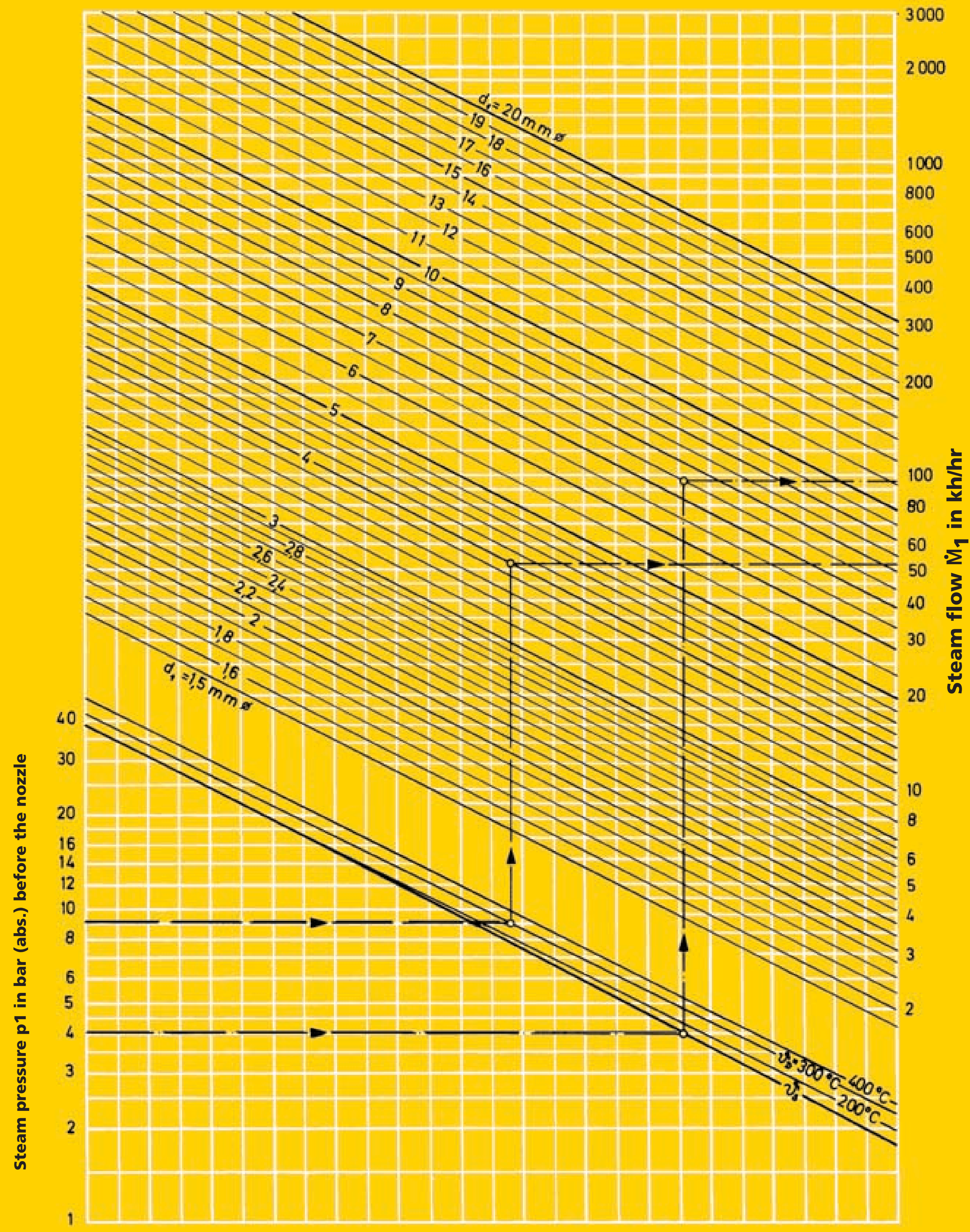
1. 96 kg/hr steam pass through the nozzle at saturated steam of p_1 = 4 bar absolute pressure and a nozzle diameter of 7.5 mm.

2. Approx. 53 kg/hr steam pass through a nozzle with a diameter of 4 mm at superheated steam (= 300 °C) with an absolute pressure of p_1 = 9 bar.

Depending on the condition of the steam either the curve for saturated steam (ϑ_S) or the corresponding temperature curve (ϑ_V) for superheated steam should be used.

Lit.:
1) VDMA-information sheet Nr. 24294, Sheets 1 and 2
2) DIN sheet 28 430

Steam Flows through Motive Nozzles



ϑ_S = Saturated steam temperature
ϑ_D = Steam temperature
d_1 = Motive nozzle diameter

Fig. 1 Steam flow through motive nozzles at critical pressure ratio

GEA Jet Pumps GmbH
Einsteinstrasse 9-15 D-76275 Ettlingen
Tel.: +49 - 72 43 / 7050 Fax: +49 72 43 / 70 53 51
Email: info@geajet.de Internet: www.geajet.com

Wiegand Technology