Gas-Solid-Ejectors: Design Variants and Applications

KS-Engineering

Niehler Str. 151-153, 50733 Cologne, Germany

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1. Introduction

Gas-solids-ejector transport systems have been known for a long time now and have already been the subject of detailed investigations [1-5]. Whereas ejector transport has previously been considered under its basic and/or theoretical aspects, and also the advantages and disadvantages compared with other transport processes have been worked out, we shall now be dealing primarily with the diverse variations in ejector design and their possible practical applications. On the basis of concrete job requirements ejector design, dimensioning and material selection will be explained and the potential customer provided with the detailed information which he can use for design considerations.

2. Features of Ejector Transport – An Overview

2.1 Functional Principle

The successful use of the gas-solids-ejector as a feeder and/or transport device in a pneumatic transport line is based on the dynamic sealing of the pressurised transport line against the dosing organ arranged above the intake zone. The potential pressure energy of the driving medium (usually air) is converted in the driving nozzle into kinetic energy. As a result, and given correct design, a slight negative pressure which favours the intake of transport material is set up in the intake zone. Material is, in short, "sucked" into the transport line. In the downstream diffusor, the kinetic energy is converted back into potential (pressure) energy again, since this is the type of energy required for the subsequent transport of the material. On account of the substantial frictional losses (wall friction, inter-molecular friction) which occur particularly at high speeds in the driving and catchment nozzles, and also in the first diffusor section, and the losses involved in accelerating the material, the initial potential energy available before the ejector cannot be completely recaptured in the diffusor. A measure of these losses is the gas-solids-ejector efficiency, whose value may be in the range of 0.2 to 0.7, depending on the quality of the design, the material to be transported and the material load.

2.2 Advantages compared to other Feeding and/or Transport Processes in Dilute Phase Conveying (e.g. Rotary Valve Systems with Feed Shoe, Screw Pumps etc.)

As already stated in topic 2.1, the greatest advantage of gas-solids-ejector resides in the negative pressure mode of operation. With other systems, leakage air, which always occurs in the absence of dynamic sealing, may either lead to increased wear in the proportioning organ (e.g. rotary valve) or may act as a hindrance to material intake. This is in particular the case with material which does not flow easily, very light or fine-grained flows, as well as bulk materials which exhibit a high air retention capability and an inclination to bridge formation (e.g. slaked lime, filter dust). Further advantages of ejector transport are its very dependable operation with continuous material input, the low maintenance requirement and, as the further description will show, its very wide range of application. Finally, ejector transport is characterised also by the low cost for instrumentation and control technology.

Dipl.-Ing. Jan Behrendt
Ingenieurbüro Schneider für Umwelt & Verfahrenstechnik

2.3 Advantages compared to other Feed and/or Transport Processes with Dense Phase Conveying (e.g. Ejector Vessel Transport, Screw Pump):

The advantages essentially lie in the lower capital investment requirement for an ejector conveyor system, which results from lower component and control equipment costs. Further advantages which should be mentioned are:

- Higher temperatures are possible
- Less inclination to plugging
- Continuous operation.

With dusts which tend to caking, continuous operation has considerable advantages. Batch processing with pressure vessel conveyors, where the material in some cases stands in the vessel for long periods, can lead to very considerable problems, for example due to caking.

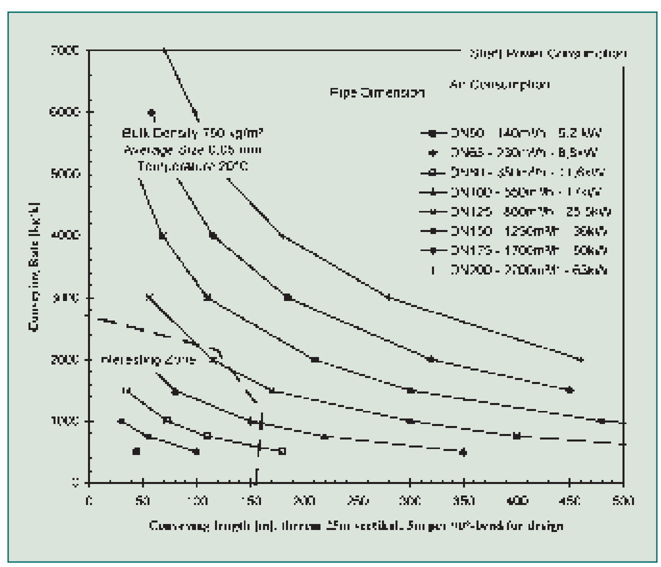
2.4 Disadvantages Compared to other Feed and/or Transport Processes

The limitations on the possible applications concerning transport capacity and transport distance can be cited in the first place as the major disadvantages of ejector transport. The reasons are primarily rooted in the energy consumption required by ejector transport. The energy losses described in 2.1 and the energy input required on account of the material load which is limited in general to 3 - 4, mean that other systems are better for high carrying capacities and/or longer transport distances.

2.5 Limitations on the Use of Ejector Transport

Fig. 1 presents the favourable field for ejector transport with regard to transport capacity and transport distance which results from the explanations in section 2.1. The attainable transport capacity with the respective equipment dimensioning is plotted against the transport distance. The curves result from a calculation of the pressure drop with well-known calculation methods for a typical boiler ash from the 2nd pass in a refuse incineration plant. Since the attainable transport capacity also depends on the material characteristics (such as for example density and particle size/size distribution), the transport curves for other materials may

Fig.1: Scope of ejector transport



be different from these. In the parameter key, the design data of the Roots blowers (air quantity, shaft power consumption) which are mainly used as the air suppliers are listed as required for the dimensions of the transport line. The energy demand for the transport of 3 t/h over a distance of approx. 60 m is, as can be seen, at approx. 25 kW quite high, and its practical realisation presumably therefore reasonable only in exceptional cases (Application 2, see below). Other transport processes are therefore preferred in those areas where ejectors are not a feasible possibility.

It should be noted that this representation only provides a rough indication for the feasibility of ejector transport. An individual consideration and a confirmatory calculation is absolutely necessary for every individual problem.

3. Standard Ejectors: Typical Applications

The standard line of products is characterised by a robust and compact design. In effect, the ejector is a casing (welded steel construction) into which the nozzle and the diffusor are inserted and fixed in position. The nozzle is adjustable, while the diffusor can be easily replaced (as a wear part). The ejector is equipped as standard with an inlet pressure gauge. An inspection opening can be integrated upon request. Depending on material properties, the bottom may be blanked off or executed as a fluidising floor. The ejector is described more detailed in [1].

3.1 Problem: Wear Behaviour of the Bulk Material

The example considered is the transport of boiler ash from the 2nd pass of a North German RIP. The conveying plant has been in operation for one year. The requirement was as follows:

Bulk material:	Boiler ash from 2nd pass of an RIP
Bulk density:	approx. 700-800 kg/m^3
Particle size:	approx. 0-3 mm
Temperature:	approx. 80°C
Transport capacity normal:	approx. 600 kg/h for 7000 h/a
Transport capacity max.:	approx. 800 -1000 kg/h
Transport distance:	45 m to an ash silo, 25 m thereof vertical
Bends:	4-off, ea. 90°

A pressure drop calculation (as well as a glance at Fig. 1) shows that the required dimensioning of ejector and transport line is DN 80. A Roots blower was selected on the basis of the design data of 350 m^3/h volumetric flow intake condition) and 800 mbar pressure boost (15 kW motor). The ejector itself is constructed completely of St 37-2. In the transition, a check valve is arranged which opens at a defined negative pressure and thus allows leakage air to enter the transport line as well. By this way, the check valve prevents too great an increase in negative pressure in the intake zone of the ejector at lower transport capacities. The ash falls continuously from the hopper of the 2nd pass, bigger crusts or agglomerations being comminuted and/or separated in a primary crusher. The bends of the transport line are not lined with cast basalt but with Al_2O_3, as is a straight section behind every bend.

On account of the special transport conditions in the diffusor (high velocities, strong turbulence), the choice of material is especially important for this unit. The hardness of the diffusor material must be greater than that of the transport material. Since strands form close to the wall in the diffusor, the use of steel diffusors (even when hardened) leads to erosion, as Fig. 2 clearly shows. These strands can continue into the first transport line section as well, so that this area too is endangered and has to be lined correspondingly. In the application considered here, a special ceramic compound has been selected for the diffusor (Si/SiC). Silicon carbide is characterised by especially great hardness and guarantees a decisive increase in life compared to steel designs.

3.2 Problem: High Temperature, High Transport Capacity

Under consideration here is the fluid bed cooler de-ashing system (emptying during disturbances and inspections, 2 transport lines) for the circulating fluidised-bed firing system in a CHP plant. This example is a somewhat specialised application of ejector transport (outside the favourable field as shown in Fig. 1). The job requirement was as follows:

Bulk material:	Circulating ash from a fluidised bed in a CHP station
Bulk density:	approx. 1200 - 1500 kg/m^3
Particle size:	approx. 0-1 mm
Temperature to:	450°C
Required transport capacity:	approx. 3500 kg/h per line
Transport distance:	26 m into the dipper pot of the cyclone return pipe, 15 m thereof vertical,4 bends of 90° each

The size of the lines was DN175 in both cases. The reserve blower for the sealing pot fluidisation with the following ratings: approx. 1500 m^3/h volume flow at intake, approx. 800 mbar boost, 110 kW motor, serves both transport lines. A dosing organ could be dispensed with in this case since the circulating material is very easily flowing. The ejector simply draws the material out of the boiler circulation direct.

The difficulties here were on the one hand the complicated routing of the transport lines (due to circumvention of existing plant equipment) and the need to allow for temperature expansion in the lines (selection of expansion joints, spring and constant hangers, short-term maximum temperatures around 500°C), and on the other hand the design of the ejector, in particular the diffusor. For the DIN 175 design this had to have an external diameter of approx. 225 mm and a length of somewhat less than 900 mm. Normally such a construction would be machined from the solid (outside as well as inside contours). However, due to the considerable weight involved, the diffusor was constructed in three parts which were then bolted flush together. Further, it proved possible by suitable profiling to obtain a weight reduction of 40% on the initially anticipated weight (slightly under 200 kg). 16Mo3 was employed as the material for the ejector, diffusor and transport lines alike. In spite of their vulnerability to wear when transporting this bed ash, the bends were left unlined. This was possible due to the short duration of service (4 - 5 times per year for approx 30 - 40 h in each case). Further it had to be guaranteed that transport would be stable over a wide temperature range for the circulation material (approx. 100 - 500°C) and

Fig. 2: Erosion by high-wear coarse ash on a steel diffusor after transport

therefore the transport speed (10..20 m/s in view of the temperature field and the air quantity) had to be fairly constant as well.

The plant was started up for the summer inspection. Because of internal operational delays the fluid bed cooler contents had however cooled down to approx. 250°C before the ejector plant could be started. This meant a relatively slow transport speed which is unfavourable for the system. The measured outside temperature of the transport lines was between 160°C (start) and 125°C (end). The speeds achieved in the line were thus only approx. 65% - 70% of the design value. Nevertheless, a very regular transport with high capacities was achieved. The evaluation of the furnace pressure measurement records (an indication of the bulk material height in the furnace) yielded a transport capacity of approx. 2 x 6.5 t/h, i.e. almost twice as high as could be expected from the design figures. Of assistance here was the bulk material column height of approx. 2000 mm above the ejector.

The example shows that ejector transport can produce good results even under difficult conditions (temperature range, dimensioning, transport line feeder) for manageable investment costs.

3.3 Problem: Bulk Material tends to cake on rigid Walls

Under consideration here is slaked lime transport for the direct desulphurisation of a bituminous coal-fired travelling grate boiler in a South German power station: The basic design parameters were as follows:

Bulk material:	Slaked lime $Ca(OH)_2$
Bulk density:	approx. 450 kg/m^3
Particle size:	approx. 0 - 0.1 mm
Temperature:	approx. 20°C
Required transport capacity:	approx. 0-200 kg/h in continuous operation
Transport distance:	55 m, 15 m thereof vertical, 5x90° bends
Transport destination:	Distributor before nozzling into the boiler

One problem with pneumatic transport of slaked lime is that with relatively small loads and at velocities above approx.15 -18 m/s, slaked lime adheres to fixed walls and undergoes partial cementation to limestone $CaCO_3$. The mechanisms causing this are the dehydration of $Ca(OH)_2$ to CaO (supplemented by the frictional/shock energies released) and the subsequent reaction with atmospheric CO_2.

As a result, pipelines or ejector diffusors of steel can become blocked until the transport breaks down. However, by using suitable materials the blockage of these items can be avoided or greatly reduced. In particular rubber hoses are to be preferred over steel piping for the lines. The flexible soft surface has a self-cleaning effect and causes any caking to flake off. However, when laying the rubber transport hoses it must be ensured that these do not sag, since this seriously affects the transport capacity of the plant. The diffusors are also executed in soft and flexible material (special rubber compound).

For the usual applications as well as those described here, dimensioning to DN 50 is sufficient to accomplish transport and feeding with sufficient safety. A Roots blower rated at 150 m^3/h intake volume flow and 800 mbar boost was selected for the air supply (7.5 kW motor).

A special problem occurs when taking slaked lime from the storage silo and dosing it into the transport organ. Slaked lime usually does not pour readily and tends to bridging - but when fluidised it goes in the other direction and avalanches very easily. The presence of fluidisation or infiltration air (see Section 2.1) is a considerable nuisance since slaked lime has a high air retention capability (GELDART classification C). Delivery then becomes very uneven, since stages with air take-up and bridging alternate with stages in which the material avalanches very fast. Suitable organs for regulating material feed are e.g. a screw conveyor with combined agitating arm or, as in the example considered here, a vibrating bottom with subsequent vibratory dosing screw.

Dimensioning of the ejector, transport line and blower is of decisive importance especially in direct desulphurisation, since at the end of the transport line there is in most cases a distributor acting uniformly over 2 - 6 outlets, which lead over shorter and smaller hoses to the injection nozzles by which the material is injected into the boiler (see also [5]). The calculation of the pressure drops of these last-named elements must be carefully incorporated into the overall balance.

The plant under consideration here has operated practically trouble-free for several years. The life of the special diffusors depends very largely on the type and quantity of the impurities in the slaked lime, since the product itself is not particularly conducive to wear. The life generally cannot be predicted in advance since the (wear-causing) impurities vary from product to product.

Fig. 3 shows the three types of diffusor mainly employed in ejectors of the standard product range:

- Black enamelled diffusor, DN100, material St 52:
  The normal steel diffusor (hardened) is employed for non-wearing to slightly-wearing bulk materials, e.g. light filter ashes, plastics etc.
- Grey diffusor, DN80, material Si/SiC (silicon carbide, ceramic): The Si/SiC diffusor is used with bulk materials which are strongly wearing, e.g. fly and coarse ashes, circulation material from FBC plants
- Beige diffusor, DN50, soft, rubber-like special material:
  This diffusor is in particular suitable for slaked lime transport, since its resilience guards against caking (self-cleaning effect).

4. Special Applications in Pneumatic Transport with Ejectors

With the applications in the so-called medium pressure field considered under Section 2 (see also [3]), Roots blowers were without exception employed for the air supply, since the relatively great airflows with boosts of 500 - 1000 mbar required for transport in medium-pressure systems can be most economically delivered by this compressor type. In most cases no subsequent treatment (drying or similar) of the compressed air is required. Cheaper types of air compressor (fans, side channel compressors) are generally unsuitable because the pressure boost delivered is too small for medium-pressure ejectors. However such air compressors play an important role in transport with low-pressure ejectors, e.g. for hay or grain transport in agriculture and for the transport of granular plastic materials etc. over short distances. On the other hand, compressors with high final pressure outputs are uneconomical with larger airflows if the supply pressure required at the consumer (medium-pressure ejector) is only a maximum of 1 bar g.

However, there are applications in which the high-pressure region does become interesting again. This applies mainly to small carrying capacities (e.g. 0 - 30 kg/h) and the use of so-called high-pressure ejectors. The motive power can often be tapped from an existing works compressed air mains, but the procurement of a small mobile compressed air unit (compressor, separator, drier, filter) is not unduly expensive for consumptions which in most cases are under 80 m^3/h STP. Below, some examples in which ejectors have been designed and constructed in particular for high-pressure applications are described.

4.1 High Pressure Ejector for the Transport and Atomisation of Gas/Solid Mixtures

In process engineering it is often necessary to admit solid materials in a finely distributed form into a reaction vessel with optimum effect. For example, in flue gas cleaning sorbents must be

Fig. 3: Diffusors of the standard ejector types, with different dimensions and materials

injected into flue gas ducts or furnaces and dispersed there for effective emission control. An adequate depth of penetration and jet dispersal/mixing are important here.

The newly developed high-pressure ejector solves these tasks and furthermore is still able to suck in the sorbents over a short distance (a maximum of approx. 10 m). In this way it is possible in smaller plants and for short distances to dispense with the pneumatic transport system which would otherwise be required. The ejector is basically a special adaptation of the well-known Coanda ejector as described for example in [1]. The transport material enters axially and runs through the central tube which has no constriction and is therefore especially advantageous in the case of sorbents which tend to plugging. An air film coaxially emerging over a slit envelopes the solid material and/or the nozzle outlet and mixes with the sorbent. An excellent dispersion of the solid matter is achieved by the high velocities in the slit and the marked shear slope in the air jet. The angle of dispersion of the air/solid mixture can be influenced by the nozzle profile. Usually loads of approx. 0.5 to 3 kg solid matter per kg air are possible.

The air is mostly taken from the existing compressed air mains at 6 - 7 bar gauge or produced in a small mobile unit on site. The air quantity depends on the solid substance to be transported and/or atomised and the conditions in the reaction space, in particular if there is overpressure there. Without further assistance, back- pressures up to approx. 80 -100 mbar g can be overcome. The characteristics of such a high-pressure blowing ejector are shown in Fig. 4. The desired operating point and the degree of atomisation can be adjusted by varying the size of the gap. The transport air must be dry (cold dried as a minimum standard) and free of oil and particles. Air quantities and pressures can be checked with a flow meter and pressure gauge. The ejector can be easily connected over a pipe flange (here DN100) and tubular nozzle with the reaction space (see Fig. 5).

Summarising, it can be said that the new high-pressure ejector solves the partial tasks

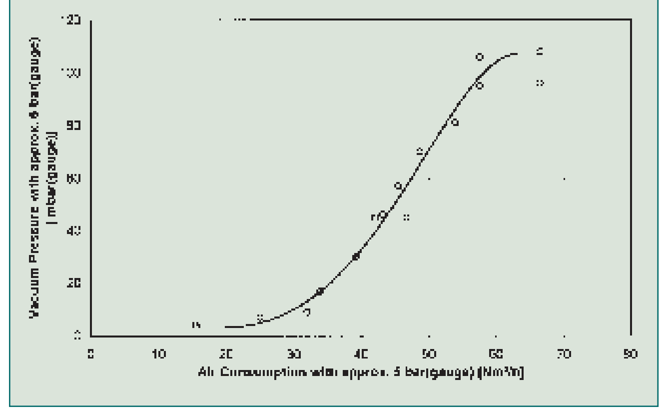


Fig. 4: Characteristics of a high-pressure ejector

* Good dispersion,

* Defined penetration depth and

* Pneumatic intake over short distances

in a simple, space-saving and reliable manner. Considerable costs can be saved because of the minimal design of such an ejector plant. Testing in situ is easy and simple.

Favoured areas of application are flue gas cleaning, for example in waste incineration plants, where nozzling into the flue gas duct takes place at slight negative pressure in the duct.

Fig. 5 shows the ejector during a special campaign (compressed-air supply green, soft suction hose black, pressure gauge line grey). It is installed in a bend of a 350 mm GRP line and disperses approx. 1 kg/h activated carbon in co-flow into the process gas, in order to bind unwanted dioxins and similar pollutants. The plant can be operated with an air requirement of approx. 60 m^3/h STP(using dry compressed air at 6 bar from the factory mains) without assistance even up to a back-pressure of 120 mbar g in the transport line. Dosing is via a specially constructed frequency-operated proportioning screw. If the back-pressure in the line rises to more than 120 mbar g, the dynamic pressure barrier is no longer sufficient and process gas escapes backwards as a result. In this case the arrangement described below can be used.

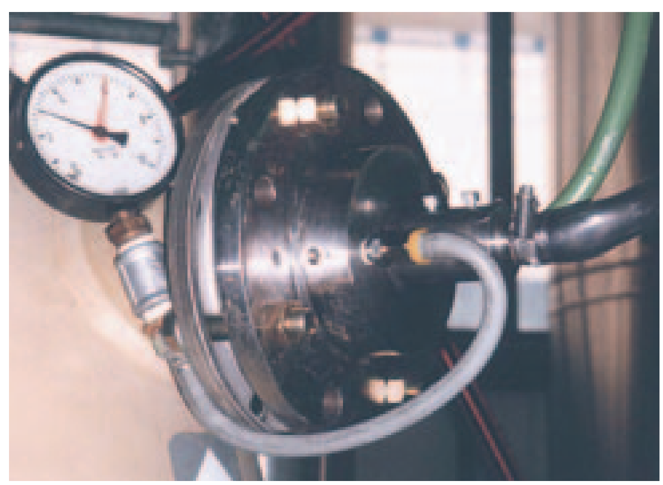


Fig. 5: High-pressure ejector for the transport of sorbents and dispersion in a reaction space

4.2 Mini High-Pressure Ejector, here as a driving Ejector

The mini high-pressure ejector (stainless steel) shown in Fig. 6 was employed in the ejector plant described above as a driving

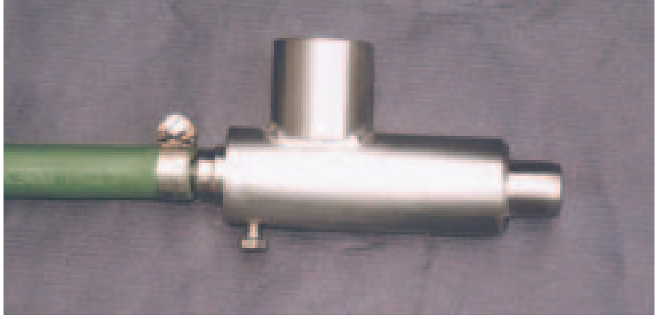


Fig. 6: DN 12 high-pressure ejector in stainless steel

ejector to overcome process back-pressures of up to 200 mbar g together with the downstream ejector. The material feed (in the photo above) was connected to the outlet of the proportioning screw, the transport end with the suction hose of the ejector already described. With this combination transport could be successfully maintained. The intrinsic air requirement of the driving ejector amounts to approx. 10-15 m^3/h STP (dry compressed air at 6 bar from the works mains).

The design of high-pressure ejectors presupposes knowledge and application of the fluid dynamics processes taking place in the ejector. The profile of the nozzle must for example be approximated as precisely as possible to a Laval nozzle so that the high pressure jet can expand without causing compression surges in the ultrasonic field.

With ejectors of this size the properties of the bulk material to be transported assume special importance. Materials should be free-flowing and dry, since the feed organs are otherwise prone to plugging because of the small cross-section. The material feeding must also be extremely uniform in order to avoid overcharging and the transport problems resulting therefrom.

4.3 High pressure ejector in modular design for different nominal cross-sections

For test purposes a high-pressure ejector (Fig. 7, material stainless steel) was developed which can be used for different nominal diameters of the downstream transport line (here DN 25 and DN 32) and therefore for different bulk transport ranges and air consumptions. The ejector is designed in such a way that both nozzle and diffusor are exchangeable. For operation with DN 25 the air consumption is approx. 35 - 40 m^3/h STP, the transport capacity (powdered Al_2O_3, bulk density 800 kg/m^3, particle size 0 - 200 μm) max. 80 kg/h; as a DN 32 ejector the air requirement is approx. 55 - 60 m^3/h STP, the transport capacity max. 200 kg/h. During operation in the hypercritical pressure area (inlet pressures > 1 bar g are considered hypercritical), the compressed air flow is constant and only dependent on the set inlet pressure. Retrospective effects from the transport process, as observed during operation in the low-pressure field (inlet pressures < approx. 1 bar g are subcritical), do not occur (with the exception of total plugging). This encourages stable transport conditions and therefore a good overall performance of the conveyor.

Fig. 7: Modular design high-pressure ejector of stainless steel, optional operation with DN 25 or DN 32

The entry of infiltration air is of special importance in the case of the high-pressure ejector. Negative pressures up to 300 mbar in the feed zone were measured (in the driving ejector in Application 6). These high negative pressures are usually not desirable, since as a result to much material can be sucked in through the proportioning organ, which is not the purpose of the proportioning function and causes increased wear there as well. Simultaneously these high negative pressures are an indication that the conveyor is being operated very far from the design point. A good design in the sense of optimal energy utilisation is achieved in practice if the negative pressure in the operating condition is almost zero, or if at most a slight negative pressure exists to support material input. If the operating conditions change, e.g. by decrease in the proportioning output (within the control range), the negative pressure will automatically increase, since the energy input is constant (see above). It is then important to at least partly correct the negative pressure by permitting the entry of infiltration air. Spring-loaded check valves which open at a defined negative pressure can be used here, for example.

The interplay between ejector inlet pressure, negative pressure in the feed zone and (automatic) operation of the check valve allows simple operation of the conveyor plant. By setting the inlet pressure to a value just below the point at which the check valve opens, it is possible to quickly find the desired operating conditions.

5. Summary

Ejectors can be employed for bulk material transport in diverse applications. Through selection of design variants, suitable materials and the choice of correct dimensions, the advantages of ejector transport can be enjoyed for almost any job requirement. Here ejectors for the low- and high-pressure areas, for carrying capacities between 1 and 3500 kg/h, for high-wearing materials and those which tend to caking, for material temperatures of 20 - 500°C, as transport organs and also as nozzles for dispersion into reaction spaces have been briefly introduced.

Careful design, knowledge of the material characteristics and integration into the overall plant concept are always factors of particular importance.

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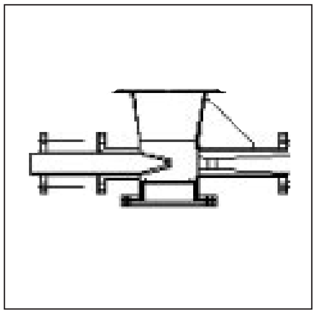
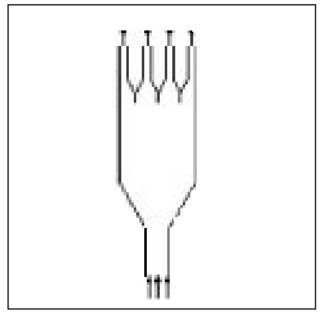
Environmental and Processing Technology

Niehler Str.151-153 • D-50733 Koeln • Germany
Tel. +49 (0)221 / 71241-33 (Fax -55)
http://www.enviro-engineering.de
e-mail: info@enviro-engineering.de





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