Gas-Solid-Ejectors: Design Variants and Applications

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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 closing 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.

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](image-url)
behind every bend.

DN 80. A Roots blower was selected on the basis of the design that the required dimensioning of ejector and transport line is

A pressure drop calculation (as well as a glance at Fig. 1) shows guarantees a decisive increase in life compared to steel designs.

con carbide is characterised by especially great hardness and

ramic compound has been selected for the diffusor (Si/SiC). Sili-

respondingly. In the application considered here, a special ce-

well, so that this area too is endangered and has to be lined cor-

These strands can continue into the first transport line section as

(even when hardened) leads to erosion, as Fig. 2 clearly shows.

form close to the wall in the diffusor, the use of steel diffusors

must be greater than that of the transport material. Since strands

(high velocities, strong turbulence), the choice of material is espe-

On account of the special transport conditions in the diffusor

The example considered is the transport of boiler ash from the

3.1 Problem: Wear Behaviour of the Bulk Material

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].

3.2 Problem: High Temperature, High Transport Capacity

Under consideration here is the fluid bed cooler de-ashing sys-

tem (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/m³

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 m³/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 rout-

ing 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 DN 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 guaran-
teed 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](image-url)
considerable nuisance since slaked lime has a high air retention. The presence of fluidisation or infiltration air (see Section 2.1) is a necessary condition for the transport of slaked lime. Slaked lime does not pour readily and tends to bridge, but when fluidised, it takes a cohesive but non-caking form. A special problem occurs when taking slaked lime from the storage hopper into the boiler of a South German power station: The basic design parameters for the transport of slaked lime to the boiler are as follows:

Bulk material: Slaked lime Ca(OH)_2
Bulk density: approx. 450 kg/m³
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

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 high airflows are 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 m³/h STP. Below, some examples in which ejectors have been designed and constructed in particular for high-pressure applications are described.

4. Special Applications in Pneumatic Transport with Ejectors

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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...
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

- 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 m³/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.

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
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 opens, it is possible to quickly find the desired operating conditions.

With materials 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.

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 for different bulk transport ranges and air consumptions. The ejector is designed in such a way that both nozzle and diffuser are exchangeable. For operation with DN 25 the air consumption is approx. 35 - 40 m³/h STP, the transport capacity (powdered Al₂O₃, bulk density 800 kg/m³, particle size 0 - 200 µm) max. 80 kg/h; as a DN 32 ejector the air requirement is approx. 55 - 60 m³/h STP, the transport capacity max. 200 kg/h. During operation in the hypercritical pressure area (inlet pressures > 1 bar 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 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.

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.

References

KS-ENGINEERING DELIVERS:
• Ejectors
• Pressure Vessel Conveyors
• High Pressure Injection Nozzles
• Manifolders for Conveying Lines
• Conveying Plants
• Injection- / Fluidizing Technology

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