APPLICATION OF AN INJECTOR FOR EVACUATING CHEMICALLY AGGRESSIVE GASES

PRIMENA INJEKTORA ZA OTSISAVANJA HEMIJSKI AGRESINIH GASOVA

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ABSTRACT

The injector is a fluid machine of simple construction, featuring no moving parts. It is fluid stream machine. Should there be an occasional need for exhausting chemically aggressive fluids, this machine proves very convenient on account of its lower purchase price compared to other types of hydraulic machines. The injector discussed in this article has been originally designed for exhausting gases from the sulphur chamber, which is used in the pretreatment of fruit before drying. Once the sulphuring is completed, the SO2 gas should be exhausted promptly.

Under realistic sulphuring conditions, the effect measurement was performed at a compressed air pressure of 2 bar. The compressed air pressures ranged from 0.5 to 2.5 bar. In the instance when the chamber was filled with fruit, at a pressure of 2 bar, the ratio between the exhausted and compressed air was 1.68, at an exhausted gas flow rate of 0.0327 kg/s. The volume of empty chamber was 0.2856 m3. According to these data, a period of 10.04 s is required for one air change in the chamber. As complete aeration of the empty chamber necessitates three air changes, the injector should be in operation for 30.12 s.

Key words: injector, hydraulic machine, chemically aggressive gases, sulphuring.

REZIME

Kada su u pitanju, fluidi koji sadrže hemijski agresivne komponente, mora se viditi računa o tome da je izabrana hidraulična mašina izrađena od materijala koji su otporni na dejstvo baznih ili kiselih tečnosti. Rutinski izbor hidraulične mašine se u ovakvim slučajevima, svodi na izbor hidraulične mašine koja ima bar radne organe (lopatice, klipove, krila i sl) od nerđajućih materijala. Ovakve mašine su uglavnom znatno skuplje od onih koje su izrađene od konvencionalnih konstrukcionih materijala.

Primena strujnih hidraličnih mašina (injektora) dosta je retka, uglavnom zbog nepoznavanja efekata rada, ali i zbog nepostojeće adekvatne ponude koja bi omogućila projektantu tehnoloških postrojenja izbor i ugradnju.

Projektovan je namenski injektor uz kriterijum da ne bude skup, a da zadovolji potrebe odsisavanja vazduha u kome ima SO_2. Odsisavanje ovog gasa iz komore za sumporisanje voća treba da bude obavljeno za nekoliko minuta. Za realne uslove sumporisanja obavljeno je merenje efekata za slučaj kada je pritisak komprimovanog vazduha bio 2 bar. Pritisci komprimovanog vazduha bili su od 0,5 do 4,0 bar. Za slučaj kada je komora bila ispunjena, a pritisak bio 2 bar, odnos odsisanog vazduha i komprimovanog vazduha je 1,68, pri protoku od odsisanog vazduha od 0,0327 kg/s. Zapremina prazne komore je 0,2856 m^3. Prema ovim podacima jedna izmena vazduha u komori obavi se za 10,04 s. Ako se uzme da je za potpuno provetravanje prazne komore dovoljno tri puta izmeniti vazduh, tada je dovoljno da injektor radi 30,12 s. Za to isto vreme u ispunjenoj komori vazduh se izmeni 4-5 puta. Injektor se uključuje na kraju procesa sumporisanja, koji, inače, traje 2-3 h.

Ključne reči: injektor, hidraulična mašina, hemijski agresivni gasovi, sumporisanje.

INTRODUCTION

A vast number of technological devices feature the flow of different fluids. The forced flow of such fluids through the device is generated by operating hydraulic machines such as fans, compressors and pumps. Technological devices are fitted with operating hydraulic machines of various size and construction. In dealing with chemically aggressive fluids, the hydraulic machine of choice should be constructed of materials resistant to base and acid fluids. However, gases can also contain aggressive constituents such as sulfur and nitrogen oxides, which form acids when dissolved in water (moisture). The usual selection of hydraulic machines under these circumstances entails machines featuring stainless implements (namely blades, pistons, vanes, etc.). Therefore, such machines are considerably more expensive than those constructed of convectional materials.

The rapid development and theoretical study of injectors commenced in the middle of the nineteenth century, primarily aimed at improving locomotive facilities (*Pochet, 1877*).

However, the contemporary automobile industry has drawn renewed attention to comprehensive studies and technical applications of injectors as they enhanced the performance and cost-effectiveness of engines (*Crawford, 2003*).

The application of fluid-flow hydraulic machinery is fairly uncommon in process engineering mostly due to the lack of knowledge about the operational effectiveness of such machines and the lack of adequate equipment for designing and constructing technological facilities. Only few facility designers wish to engage in constructing such machines for specific purposes. The injector is a fluid-flow operating hydraulic machine which can be readily used under the circumstances stated above. This machine features no movable parts, which is one of its distinct advantages, and operates on the principle of injecting the primary fluid into the flow of the main fluid being transported (*Babić, 2012*). The primary fluid pressure is significantly higher than the main fluid pressure. To achieve the effect of "energy addition" to the main fluid, a convergent-divergent nozzle is used (*Voronjec and Obradović, 1979*).

Accordingly, the fluid velocity (the kinetic energy) is very high in the narrow neck section of the nozzle at the expense of a decrease in the pressure energy of the fluid (Fig. 1). The primary fluid (2) is injected in the narrow neck section of the nozzle, or immediately in front of it. The primary fluid velocity is also markedly high on account of the high fluid source pressure. An intensive mixing of the fluids occurs in the narrow neck section of the nozzle and continues in the divergent section as well. However, the fluid velocity decreases in the divergent section of the nozzle at the expense of an increase in the pressure energy of the fluid according to the Bernoulli's equation (*Voronjec and Obradović, 1979*).
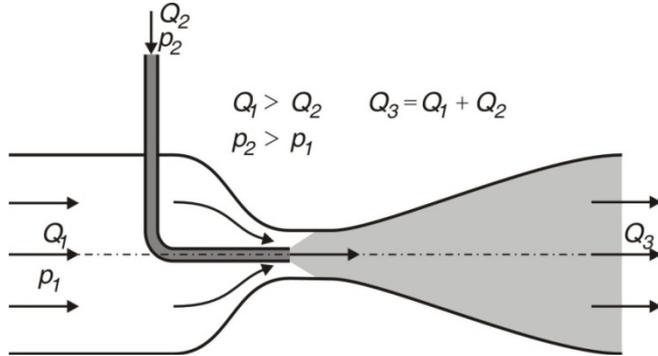

Fig. 1. Convergent-divergent nozzle (injector) (Babić, 2012)
(Q_i – air flow rate, p_i – air pressure, 1- ejected air,
2 – injected air and 3 – outlet air)

Fluid energy conversion can be more or less efficient in the injector, but the lack of movable parts is a great advantage of this machine. Provided chemically aggressive fluids are used, the convergent-divergent nozzle can be made of stainless steel, ceramic, or some other chemically resistant materials. In accordance with contemporary fruit drying methods (*Kudra and Mujimdar, 2002; Babić and Babić, 2012; Babić et all, 2005*), a combined technology for drying fruits and other biomaterials was developed at the Faculty of Agriculture, the University of Novi Sad (*Babić, M. et all 2012*). This technology utilizes the osmotic pre-drying treatment in a sucrose solution, or other suitable solutions (*Babić et all, 2009*). The equipment, which is a pivotal part of the combined drying technology, is of original design. One of the most important devices within this facility is a sulfurization chamber, in which the sulfur dioxide treatments of biomaterials take place for the purpose of their antibacterial and antioxidant protection. Upon the end of the treatment process, the air containing significant amounts of SO_2 needs to be evacuated. In contact with moisture, SO_2 forms sulfuric acid, which is extremely chemically aggressive. Therefore, the injector is required to perform a simple evacuation of the resulting mixture of air and SO_2. This device was designed to be cost-effective and of simple construction.

The purpose of this study is to examine the effectiveness of the device designed and elucidate whether such a device would perform the intended function. Moreover, the existing device will be rendered more energy-efficient without a significant increase in costs.

MATERIAL AND METHOD

A self-designed injector disposed at the top of the sulfurization chamber was examined in this study (Fig. 2). Air is injected into the device under high pressure. The injector was designed to be cost-effective and of simple construction because of its short use period upon the end of the sulfurization process.

Moreover, it was designed to feature conic convergent and divergent sections, as well as a cylindrical narrow neck section. An experiment was conducted to determine the effect of the injected air pressure on the chamber evacuation. Furthermore, favorable parameter values of the injector operation were set relative to the time required for evacuating the air mixture from the sulfurization chamber.
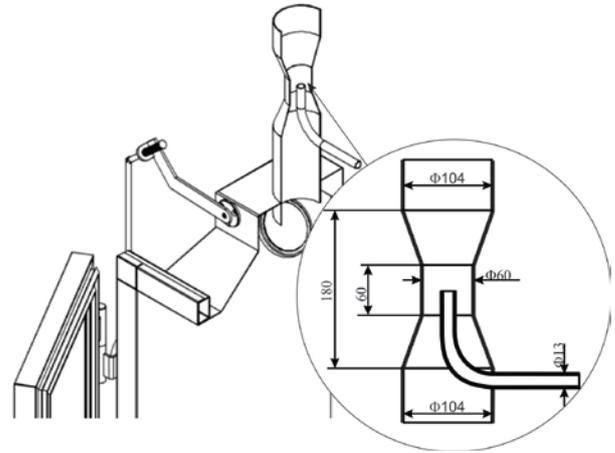

Fig. 2. Position and dimensions of the injector

Measurements of the flow and condition of the air injected were performed, as well as measurements of the total flow and condition of the air released into the atmosphere (Fig. 3). Measurements of the condition of the surrounding air were also performed, namely the dry-bulb temperature (t_o), the wet-bulb temperature (t_{om}), the mass flow rate of the air injected (using a Coriolis mass flow meter), and the pressure of the air injected (using a Bourdon pressure gauge). A pipe section was fitted at the air outlet to uniform the air velocity profile in the pipe cross section. In addition to the condition of the outlet air (namely the dry-bulb temperature (t_3) and the wet-bulb temperature (t_{3m}) of the outlet air), the outlet air flow was also measured using the hot wire method. When the measurements were performed, the device was empty with the chamber door closed. Only the small door of the furnace for powdered sulfur, in the bottom section of the device, was open.

Fig. 3. Measurement method and the device

The measurements performed involved the chamber filled with quince slices cut in half, i.e. 1/16 of a quince fruit. SO_2 was also generated to create the real conditions for the injector operation. It was subsequently established that the injector operation under real operating conditions at an injected air pressure p_2 of 2 bar required further testing. The air was injected from the existing compressed air installation using a pressure regulator. A total of three measurements of other parameter values were performed at each pressure level considered. The measurements were performed at the Laboratory for Fluid Mechanics, the Faculty of Technical Sciences in Novi Sad.

Table 1. Mass flow rates of air at different values of the injected air pressure

Injected air pressure p_2 (bar)	Mass flow rates of air (kg/s)			Ratios of the mass flow rates of air		
	Ejected M_1	Injected M_2	Outlet M_3	M_2/M_3	M_3/M_2	$R=M_1/M_2$
0.50	0.01509	0.00858	0.02367	0.362	2.762	1.7587
1.00	0.02189	0.01366	0.03555	0.384	2.604	1.6025
1.50	0.02490	0.01594	0.04084	0.390	2.564	1.5621
2.00	0.03284	0.01987	0.05271	0.377	2.653	1.6527
2.50	0.03653	0.02279	0.05932	0.384	2.604	1.6029
3.00	0,04013	0.02580	0.06593	0.391	2.558	1.5554
3.50	0.04494	0.03021	0.07515	0.402	2.488	1.4876
4.00	0.04487	0.03420	0.07907	0.433	2.309	1.312

RESULTS AND DISCUSION

On the basis of the measurements performed, the mean values of the mass flow rates of the injected air (M_2) and the outlet air (M_3) were calculated. The mass flow rate of the ejected air (M_1) was calculated on the basis of the following mass balance equation:

$$M_1 = M_3 - M_1 \qquad (1)$$

Table 1 is a tabular representation of the mass flow rates of air at different values of the injected air pressure p_2. Moreover, Table 1 shows different ratios of the mass flow rates recorded. The last column containing the R values, i.e. the ratio between the ejected air M_1 and the injected air M_2, is especially noteworthy. Using Table 1, a graphical representation of changes in the mass flow rates of air at different values of the injected air pressure was produced (Fig. 4). As can be seen in Figure 4, the functions obtained are monotonically increasing and could be approximately expressed by linear equations. The function trends obtained are as expected.
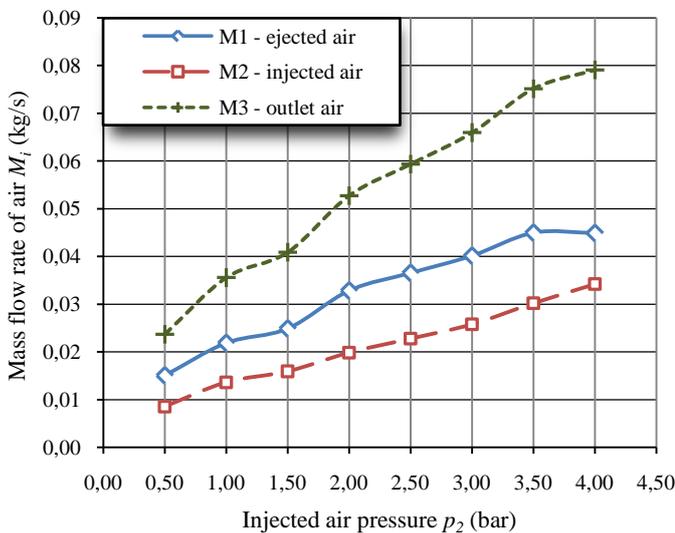

Fig 4. Dependence of the mass flow rates of air recorded on the injected air pressure

The function of the dependence between the ratios of the mass flow rates of air R and the injected air pressure p_2 is also very noteworthy, which is graphically represented in Fig. 5. Using a regression analysis, it was established that this function can be represented by the following fifth-order polynomial with a high coefficient of determination r^2:

$$R = M_1/M_2 = -0.0138\, p_2^5 + 0.1746\, p_2^4 - 0.8652\, p_2^3 + 2.0238\, p_2^2 - 2.171\, p_2 + 2.4388 \quad (r^2=0.979) \qquad (2)$$

As can be seen in Fig. 5, the local maximum value of R is recorded approximately at an injected air pressure p_2 of 2 bar. An increase in the R values was recorded at an injected air pressure p_2 of less than 1 bar with a simultaneous decrease in the total M_1 flow rate, requiring more time for the aeration of the sulfurization chamber. Therefore, measurements under the real operating conditions of the sulfurization chamber were performed at an injected air pressure p_2 of 2 bar. The chamber was filled with fruit (quince) samples at an R value of 1.68 and an M_3 value of 0.0327 kg/s. The empty chamber volume was 0.2856 m^3. The density of air was 1.15 kg/m^3. According to the data state above, a period of 10.04 s is required for a single air change in the chamber. As the complete aeration of the empty chamber necessitates three air changes, the injector should be in operation for 30.12 s, a period during which the air in the filled chamber will change 4-5 times. The injector is switched on at the end of the sulfurization process lasting 2-3 hours.
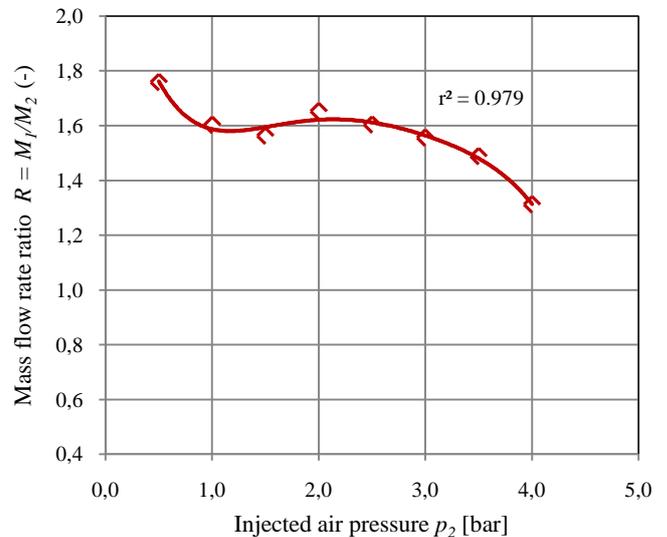

Fig. 5. Dependence of the mass flow rates ratio R on the injected air pressure

CONCLUSION

The designed injector can be efficiently used for the intended purpose. Under the injected air pressure, the chamber can be aerated in 0.5 minutes, or maximum 1 minute, which is rather fast and efficient. The improvement of the R ratio is possible by an axial movement of the injector pipe towards the corner of the narrow neck section. Moreover, using the constricted section of the Venturi pipe in lieu of the pipe conic section could decrease the air flow resistance, i.e. increase the energy efficiency, which would require further research.

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