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Experimental Study on Pneumatic Ejector, with Special Reference to the Effect of Area Ratio on Performance Characteristics (1st Report)

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Abstract

Experiments on pneumatic ejector have been conducted to ascertain the effect of the area-ratio, i.e. the ratio of the cross-sectional area of the parallel part of the mixing tube to the nozzle exit area, upon the perfomance characteristics. The compressed air delivered by a Roots blower was employed as a driving fluid, and the air sucked in from the surrounding atmosphere was used as a driven fluid. Experiments were performed under constant driving pressure with varying weight flow of the secondary air.

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I. Introduction

Various theoretical researches and experimental studies have been performed on ejectors, and especially as to the steam ejectors, many a survey was conducted that the performance characteristics and the functions of them have been thoroughly understood. Further, ejectors using oil vapor have been studied recently by Prof. S. Sugawara.[1]. The theoretical and experimental studies on pneumatic ejectors have also been conducted recently, and the results[2)3)4)] obtained are available to some extent. The present authors have conducted experimental study on pneumatic ejectors with special reference to the effect of area ratio, i.e. the ratio of the cross sectional area of the parallel part of the mixing tube to the nozzle area and have endeavoured to obtain performance data not available

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1) S. Sugawara; Trans. Japan Soc. Mech. Engrs, Vol. 20 No. 16, 1954, pp. 542 and 548
2) L. J. Kaster, J. R. Spooner; Proc. Inst. Mech. Engrs. Vol. 162 1950, pp. 149～159
3) J. H. Keenan; Jour. App. Mech. Sept. 1950, pp. 299～309
4) Ueda, Ikeno; Science of Machine, Vol. 5 No. 7, July 1953, pp. 425～429

from the preceding literatures. In our experiment, the compressed air delivered from a Roots lower was employed as driving fluid, and the air sucked in from the surrounding atmosphere was used as driven fluid. The nozzle used in the present experiment is of convergent type, and six mixing tubes having parallel part or throat of different cross-sectional areas were constructed to vary the above-mentioned area ratio of the ejector. The weight flow of the secondary air was allowed to vary by a valve, and the experiments were conducted by varying the weight flow of the secondary air for every constant upstream-pressure or the driving pressure of the nozzle. Further, pressure distributions were measured at the mixing chamber, parallel part and the diffuser downstream to the parallel part for a specified ejector.

II. Experimental Apparatus and the Experimental Method

Fig. 1 represents the schematic drawing for experimental apparatus on pneu-

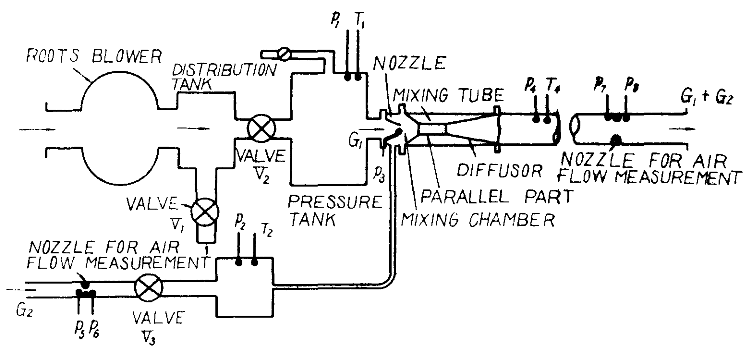


Fig. 1. Schema for Experimental Apparatus

matic ejector. The compressed air delivered by a Roots blower enters to the ditsribution tank, and then arriving at the pressure tank via valve V_2, exhausts finally out of the convergent nozzle. Another pipe provided with by-pass valve V_1 is fitted to the distribution tank, and thus the pressure in the pressure tank may be varied by the operation of the valve V_1. The valve V_2, on the other hand, has the purpose for checking the air flow when the experimental set is utilized for another purpose. Thus, for the present case, the valve V_2 was left full open. The secondary air or the driven fluid is sucked into the pipe shown below in the figure. The weight flow of this secondary air G_2 is to be measured by round type nozzle, and the air is sucked into the mixing chamber via valve V_3. The weight flow G_2 may be varied if the opening of the valve V_3 is altered. Mixing of the secondary air with primary air is undertaken at the mixing chamber, from which the air is delivered to the surrounding atmosphere after passing through the parallel part and the diffuser of the mixing tube. At the downstream of the diffuser, the total amount of air, i. e. the sum of the weight flow of primary air G_1 and secodary air G_2, is measured by another air flow meter.

Thus, the weight flow of the primary air G_1 is evaluated if necessary.

The nozzle used in our experiment is of convergent type as shown in Fig. 2.

Six mixing tubes shown in Fig. 3 are used to vary the area ratio. As shown in Fig. 3, each mixing tube is constructed of the mixing chamber, parallel part and the diffuser or diverging part, and is so constructed that the nozzle exit section situates the distance a' apart from the entrance section AA of the parallel part. The values of a' are shown below in the figure.

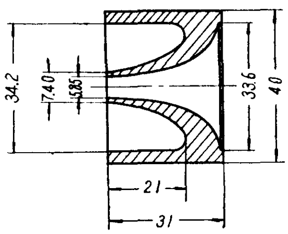
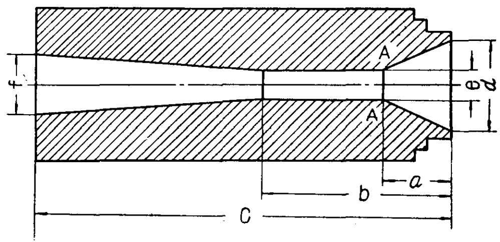


Fig. 2. Nozzle

As the inner diameter of the parallel part varies as shown in Fig. 3, we are able to vary the area ratio m, i.e. the ratio of the cross-sectional area of the parallel part to the cross-sectional area of the nozzle exit. The mixing tube ED–1950 is especially provided with several holes for pressure measurement as shown in Fig. 4. Further, the static pressures at the nozzle exit were observed by a hole drilled as shown in Fig. 10.



Test Ejector	a mm	Distance between nozzle exit and section AA, a'mm	b mm	c mm	d mm	e mm	f mm	Area ratio m
ED–1950	13.6	8.5	46.9	110.1	25.0	9.55	16.4	2.67
ED–1850	15.0	8.5	49.4	110.4	25.0	8.55	14.8	2.14
ED–1750	18.0	8.5	50.7	110.2	25.0	7.60	13.0	1.72
ED–1100	13.5	8.5	48.9	110.2	25.0	10.0	16.0	2.93
ED–1200	18.0	8.5	50.0	110.0	25.0	12.0	18.0	4.22
ED–1600	18.0	8.5	50.0	110.0	25.0	6.00	14.0	1.05

Fig. 3. Mixing Tubes

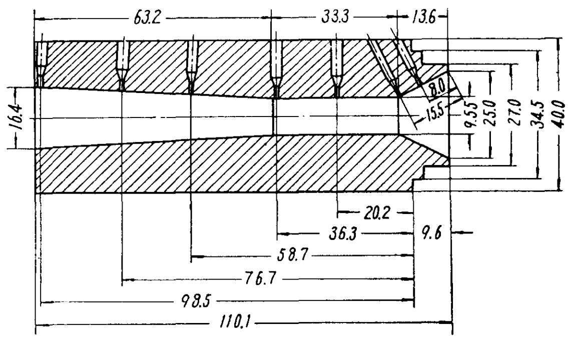


Fig. 4. Mixing tube provided with holes for pressure measurement

The situations at which the pressures and temperatures were measured for the present experimental set are shown in Fig. 1. Pressures were read by manometers filled with water or mercury, and the temperatures were observed by thermometers. The Roots blower used was driven by a 15HP electric motor of induction type, and experiments were conducted under a constant driving pressure ranging from 50mmHg to 450mmHg varying the weight flow of the secondary air from zero to maximum value.

III. The Experimental Results and the Considerations

3.1 Pressure ratio p_2/p_0 and weight flow ratio G_2/G_1.

The pressure ratio p_2/p_0 in which p_2 means the vacuum pressure in the tank (Fig. 1) and p_0 expresses the pressure of the surrounding atmosphere as well as the weight flow ratio G_2/G_1 in which G_1 and G_2 mean the weight flow of the primary and the secondary air respectively are calculated and the relations between p_2/p_0

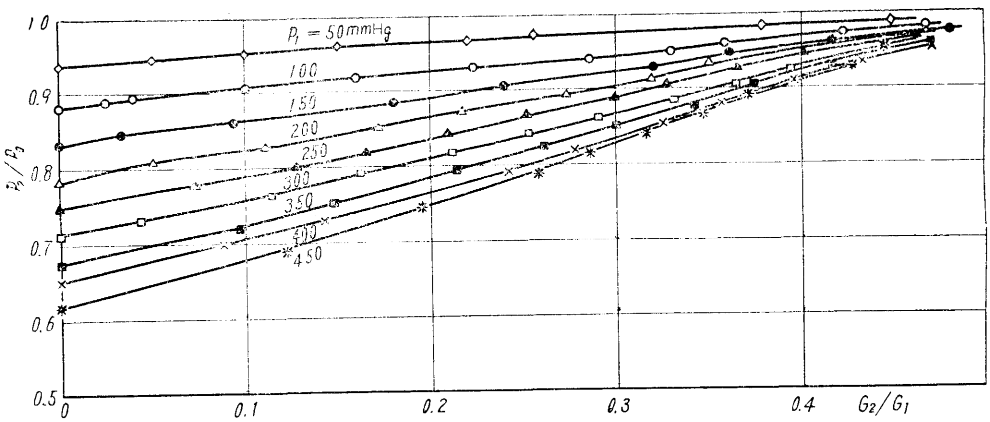


Fig. 5. Pressure Ratio vs. Weight Flow Ratio (Area ratio m=2.93, Mixing Tube ED-1100)

and G_2/G_1 are plotted. Fig. 5 shows an example of such a diagram for the case of m=2.93. The parameters of pressure p_1 is ranging from 50mmHg to 450mmHg. Fig. 6 represents the same relationships for m=1.05. When m is relatively large such as in Fig. 5, p_2/p_0 becomes smaller as the driving pressure increases, and

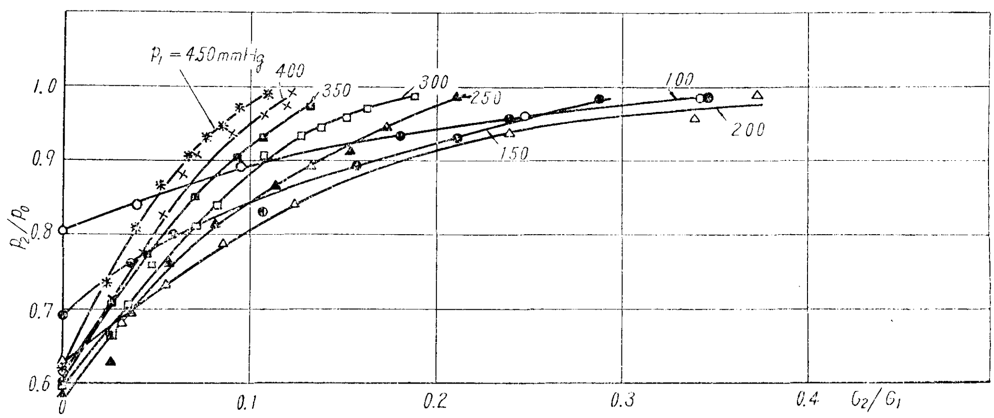


Fig. 6. Pressure Ratio vs. Weight Flow Ratio (Area ratio m=1.05, Mixing Tube ED-1100)

further p_2/p_0 increases uniformly with G_2/G_1 for every driving pressure p_1. For smaller values of m, such as 1.05, the tendency of the curves becomes somewhat different as shown in Fig. 6.[5]

When $m=1.05$ (Fig. 6), the exit area of the nozzle amounts nearly equal to the cross-sectional area of the parallel part, and thus it is conceivable that the choking phenomena of the flow at the entrance of the parallel part are liable to occur as the driving pressure p_1 increases, that is as the nozzle exit velocity and hence the weight flow of the secondary air increases. Hence we may suggest

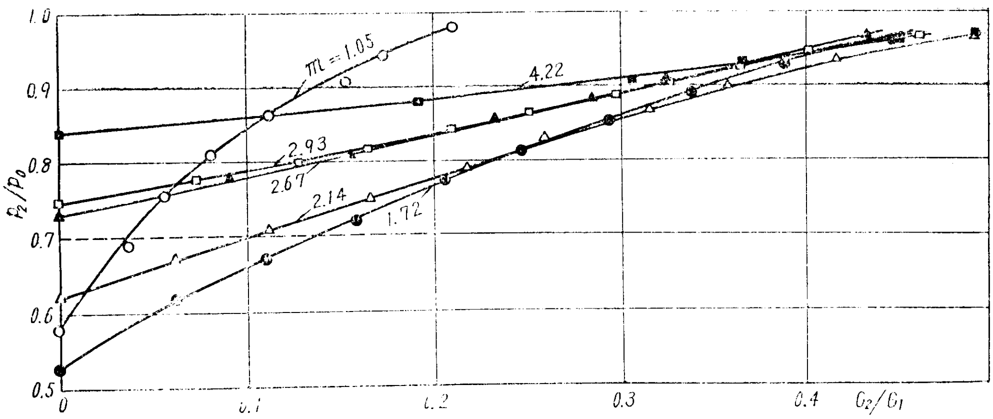


Fig. 7. Pressure Ratio vs. Weight Flow Ratio ($p_1=250$mmHg)

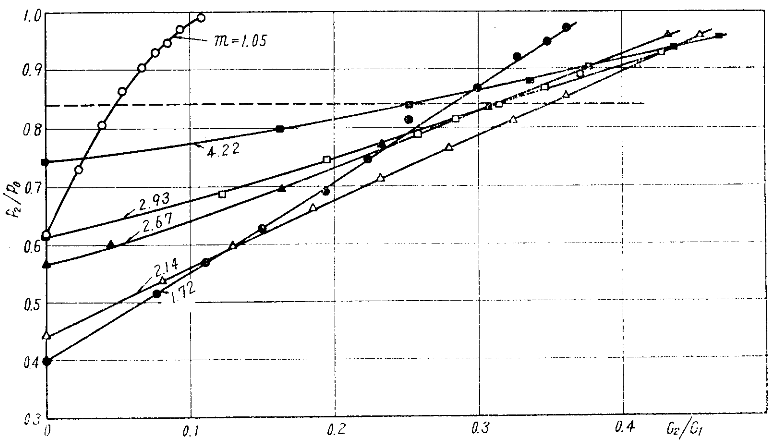


Fig. 8. Pressure Ratio and Weight Flow Ratio ($p_1=450$mmHg)

that p_2/p_0 increases or in other words the vacuum p_2 collapses rapidly as G_2/G_1 increases. For greater values of m as in Fig. 5, however, no choking phenomena are liable to occur, so that the curves show uniform tendency with respect

5) The diagrams for $m=4.22$, 2.67, 2.14 and 1.72 are not cited in the present paper. It is seen that the diagrams yield to tend gradually from the tendency shown in Fig. 5 to that in Fig. 6 as the value of m becomes smaller.

to G_2/G_1. The replotting of the curves shown in Fig. 5 and 6 for constant values of p_1 with parameters of m renders to the diagrams shown in Fig. 7 and 8. The values of p_2/p_0 corresponding to the critical value of $p_1/p_2=1.89$ amount to 0.702 (Fig. 7) and 0.842 (Fig. 8) respectively. Therefore, in the regions below these values of p_2/p_0, it is considered that the nozzle exit velocity amounts to the local sonic velocity along each curve, while in the regions above these values of p_2/p_0, the exit velocity remains subsonic and decreases gradually along respective curve as p_2/p_0 increases. Hence, notwithstanding with constant values of p_1, the nozzle exit velocity varies on each curve in Fig. 7 and 8. The choking phenomena appear clearly in these diagrams, that is, in Fig. 7, the slope of the curves becomes steeper as m decreases. In Fig. 8 where the driving pressure $p_1=450$mmHg, the choking tendency is more exaggerated compared with Fig. 7 in which $p_1=250$Hgmm.

Further replotting from these diagrams yields to the curves shown in Fig. 9

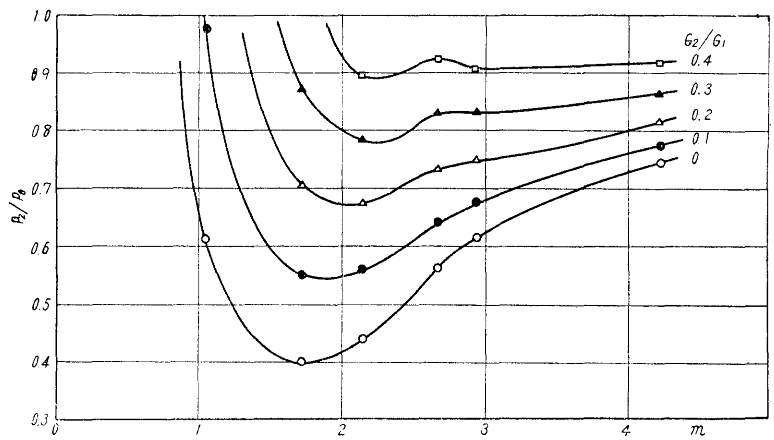


Fig. 9. Pressure Ratio vs. Area Ratio ($p_1=450$mmHg)

for the case of $p_1=450$Hgmm. The theoretical considerations[6] and the present experimental results both show that the maximum vacuum is obtained with no secondary flow. In the theoretical analysis, p_2/p_0 decreases as m becomes smaller.

The experimental results, however, show that p_2/p_0 tends initially to smaller value as m decreases until it reaches a minimum, then tending to larger value again. This phenomenon is conceivable because of the choking phenomena within ranges for smaller values of m. For larger values of G_2/G_1, the value of m which renders p_2/p_0 to a minimum removes towards larger values of m, as may be expected easily.

3.2 Pressure distributions within the mixing tube.

An example of pressure distributions within the mixing tube is shown in Fig. 10. The mixing tube used is of type ED—1950, and the pressure distributions along

6) Same as 2).

mixing chamber, parallel part and diffuser are plotted for the case of $G_2/G_1=0.4$. The pressures p_2 are also plotted in the same figure. In the theoretical treatment[7] cited above, the method of assuming constant pressure mixing in the mixing chamber has been developed. As is clear from Fig. 10, the pressures in the mixing chamber p_9 and p_{10} differ so little so far as the driving pressure is kept within the range of the present experiment, that the above method of calculus for constant pressure mixing is found to be allowable.

In the present experiment, it was found further that the static pressure at nozzle exit section p_3 shows greater value than the surrounding pressure such as p_9, even if the critical pressure ratio has not yet exceeded.

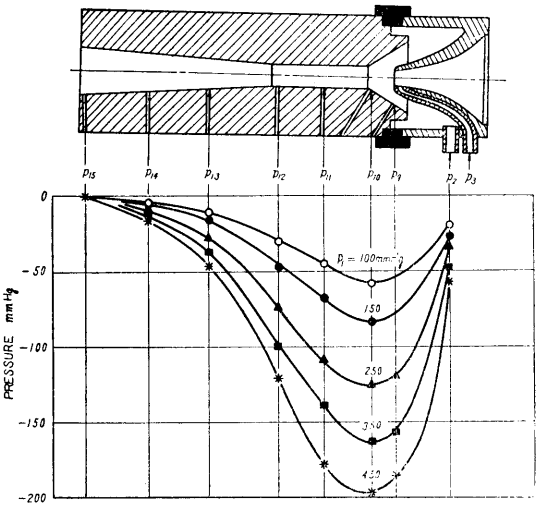


Fig. 10. Pressure Distributions within Mixing Tube

3.3 Ejector efficiencies and the weight flow ratio G_2/G_1.

The energy of the driving fluid is found to be

$$G_1\Big\{k/(k-1)\Big\}RT_0\Big\{\left(\frac{p_1}{p_0}\right)^{\frac{k-1}{k}}-1\Big\}$$

if G_1 represents weight flow of the driving fluid, p_1 expresses the driving pressure and p_0 and T_0 mean the pressure and absolute temperature of the surrounding atmosphere respectively. Further, let G_2 be the weight flow of the secondary air, p_2 and T_2 be the static pressure and absolute temperature of the secondary air before mixing. Then it is seen that the pressure of the secondary air is compressed from p_2 to p_4 i.e. the delivery pressure at the diffuser outlet (Fig. 1). Thus, if we put the velocity of the mixing stream as w_4 at the cross-section corresponding to p_4, the energy given to the secondary air yields theoretically to

$$G_2\frac{k}{k-1}RT_2\Big\{\left(\frac{p_4}{p_2}\right)^{\frac{k-1}{k}}-1\Big\}+G_2\frac{w_4^2}{2g}$$

Therefore, we may define the ejector efficiency as follows.

$$\eta=\frac{G_2\frac{k}{k-1}RT_2\Big\{\left(\frac{p_4}{p_2}\right)^{\frac{k-1}{k}}-1\Big\}+G_2\frac{w_4^2}{2g}}{G_1\frac{k}{k-1}RT_0\Big\{\left(\frac{p_1}{p_0}\right)^{\frac{k-1}{k}}-1\Big\}}\doteqdot\frac{G_2T_2\Big\{\left(\frac{p_4}{p_2}\right)^{\frac{k-1}{k}}-1\Big\}}{G_1T_0\Big\{\left(\frac{p_1}{p_0}\right)^{\frac{k-1}{k}}-1\Big\}}$$

7) Same as 3).

Fig. 11 shows the relations between η and G_2/G_1 thus obtained, when $m=2.93$. As is clear from the figure, the efficiency η falls off as the driving pressure p_1

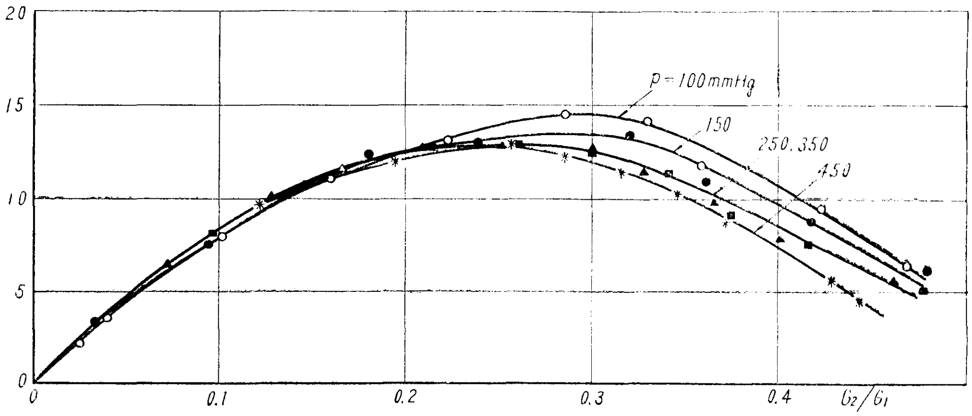


Fig. 11. Ejector Efficiency vs. Weight Flow Ratio ($m=2.93$)

becomes larger. The increase in p_1 corresponds to the increase in exit velocity from the nozzle so far as the subcritical pressue ratio regions are concerned,[8] and thus it is considered that η falls off as p_1 increases. It is also found that the values of G_2/G_1, which give maximum η become smaller as p_1 increases.

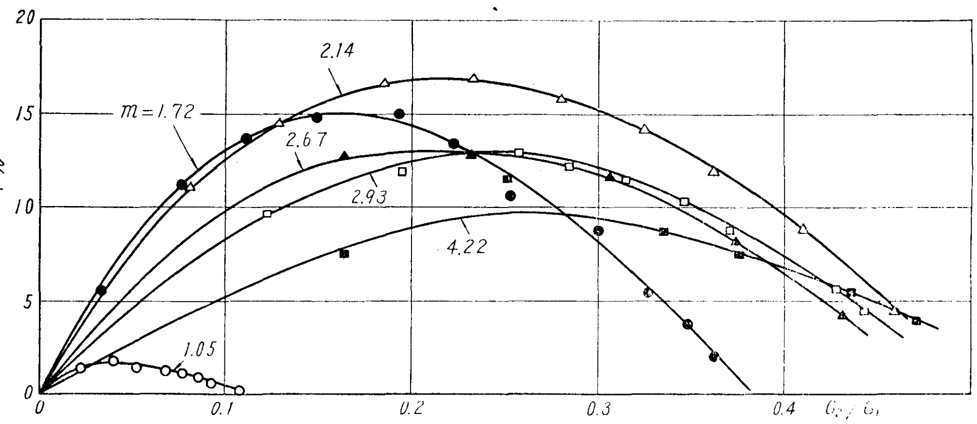


Fig. 12. Ejector Efficiency vs. Weight Flow Ratio ($p_1=450$mmHg)

Fig. 12 shows the relations between η and G_2/G_1 for the case of $p_1=450$mmHg,

8) The values of p_2/p_0 corresponding to the critical pressure ratio of the nozzle amonnt to $p_2/p_0=0.599$ and $p_2/p_0=0.633$ for $p_1=100$mmHg and 150mmHg respectively. Therefore, in these cases, the regions in the present experiments belong to the subsonic regions of the exit velocities. Thus, the exit velocity increases gradually as p_1 increases until $p_1=450$mmHg is reached, where as is seen from Fig. 8, the exit velocities amount to local sonic ones in the major part of the regions of the present experiment.

m being taken as parameter. As m tends from 1.05 to larger values, the efficiency η improves until the maximum efficiency $\eta=16.8\%$ is reached at $m=2.14$. For values of m larger than 2.14, η tends gradually to lower values. The values of G_2/G_1 which make η maximum tend as a whole to larger values of G_2/G_1 as m increases. These phenomena show qualitatively the same tendency as the theoretical results obtained by Ueda and Ikeno.[9]

IV. Conclusions

In the present experimental study, the effect of the area ratio on the perfomance characteristics has been investigated, and the following conclusions were obtained.

(*a*) The relations between p_2/p_0 and G_2/G_1 differ as m varies. When m is small such as $m=1.05$, the higher values of p_1 produce choking of the flow at the inlet of the parallel part of the mixing tube so that G_2 saturates to some value. The saturated value of G_2/G_1 tends to smaller value as p_1 increases for the same value of m. In the case of large values of m, this saturation phenomenon is not observed.

(*b*) In both cases, the minimum p_2/p_0 or the maximum vacuum is obtained whenever the weight flow of the secondary air G_2 vanishes, and the vacuum is weakened as G_2 increases.

(*c*) As is clear from Fig. 7 and 8, there exists some value of m which gives maximum vacuum or least p_2/p_0 corresponding to $G_2=0$. In our experiments, this aboslute maximum vacuum is obtained at $m=1.72$ both for $p_1=250$mmHg (Fig. 7) and $p_1=450$mmHg (Fig. 8).

(*d*) The relations p_2/p_0 vs. m for parameters of G_2/G_1 (Fig. 9) show that the value of m which gives maximum vacuum tends to larger values of m as G_2/G_1 increases. That is, if we want ejectors for small values of G_2/G_1, the lower value of m is preferable and vice versa.

(*e*) From the observations of the pressure distributions along the mixing tube, we are able to support the assumption of constant pressure mixing in the mixing chamber so far as the ejectors such as used in the present experiments are concerned.

(*f*) At a fixed area ratio m, the relations η vs. G_2/G_1 with parameters of p_1 show that the maximum value of η is obtined at smaller values of p_1. As p_1 increases η becomes smaller, and the value of G_2/G_1 corresponding to this maximum removes to smaller values of G_2/G_1.

(*g*) The relations η vs. G_2/G_1 as parameter of m reveal us that, η_{max} is affected by m, and at a certain value of m maximum η_{max}. or the absolute maximum of

9) Same as 4)

η is obtained. For values of m larger than this critical value, η_{max} becomes smaller. The values of G_2/G_1 which correspond to η_{max} become larger as m increases.