Supersonic flow of gases in pulsed Molecular beam

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Abstract

In this work the acceleration of gases in pulsed molecular beam system was studied. The relation between the stagnation pressure and gas velocity was presented. Also the relations between these values of velocities and the values of temperature corresponding to them were studied .The high value of gas velocity was obtained when we used the mixture of gas consist of (0.05 Sf_6 + 0.95Ar) with stagnation pressure equals to 1.6 bar . This value of velocity reached up to 4.48 Mach and which corresponds to temperature degree approaches to 33.4 °K.

الخلاصة:

في هذا العمل تمت دراسة تسارع الغازات في منظومة الحزمة الجزيئية النابضة .كما إن العلاقة بين ضغط السكون وسرعة الغازات قد بحثت ،بالإضافة إلى العلاقة مابين تلك القيم للضغط ودرجات الحرارة المقابلة لها . تم الحصول على أعلى قيمة لسرعة الغاز ($0.05Sf_6$+0.9Ar) وعند ضغط سكون لخليط الغازات يساوي (1.6 bar) هذه القيمة للسرعة وصلت الى 4.48 Mach والتي كانت تقابل درجة حرارة مقدارها 33.4 °K

1-Theory

Let us first consider the isentropic flow of any fluid whatsoever through a passage of varying cross section .All possible states lie on a line of constant entropy . One state on this isentropic corresponds to zero velocity. The pressure here is called the isentropic stagnation pressure. The following equations may be written for a surface extending between the stagnation section and any other section in the channel [1,2].

$$h_o = h + \frac{V^2}{2} \qquad \text{………..(1)}$$

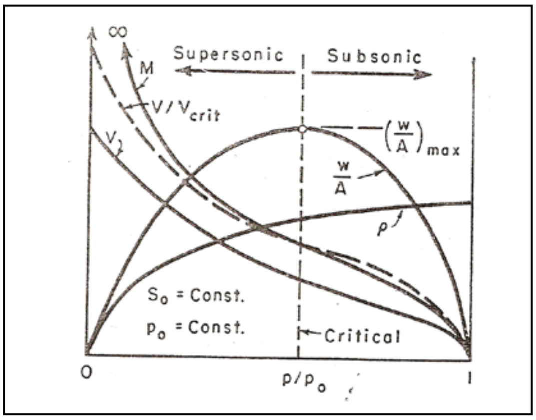
Where (h) (V) are enthalpy and velocity respectively. The second law of thermodynamics

$$S = S_o \qquad \text{…………… (2)}$$

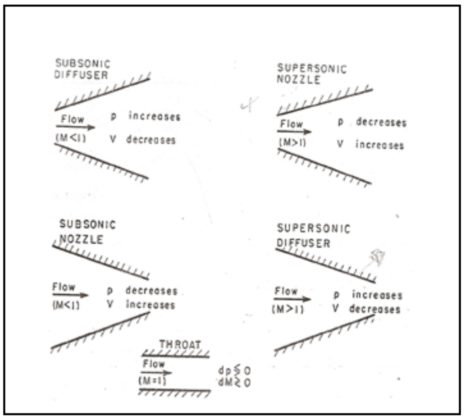
Equation of continuity

$$G = \frac{\omega}{A} = \rho V \qquad \text{………… (3)}$$

Where (W) is mass rate of flow, (A) cross –section area, (G) mass velocity, (ρ) density ,(S) entropy and (V) velocity. For a given stagnation condition (equation 1) may be used for constructing the performance curve shown in figure (1). The most interesting feature of this curve is the maximum in the curve of flow per unit area. Which indicates that an accelerating stream starting from rest must first decrease in cross section and then subsequently increase in cross section [3].The ratio P/P_o, where the flow per unit area is a maximum, is called the critical ratio, and has a value for all real gases of approximately one- half .Pressure ratios greater than the critical corresponds to subsonic flow and ratio less than the critical corresponds to supersonic flow.



Fig(1) the performance curve of the ideal gas[2]



Fig(2) The possible types of flow ducts[2]

From the thermodynamic relation [2, 4, 5]:-

$Tds = dh - dP/\rho$ …………………………(4)

And condition of constant entropy

$dh = dP/\rho$ ………………………………..(5)

$dP = -\rho V dV$ ……………………………......(6)

Since the process is isentropic

$dP/d\rho = (\frac{\partial P}{\partial \rho})_S = C^2$ ……………………….(7)

$\frac{dA}{A} = \frac{dP}{PV^2}(1 - \frac{V^2}{C^2}) = \frac{1 - M^2}{\rho V^2} dP$ ……………..(8)

Where $M = \frac{V}{C}$ (Mach number)

$\frac{dV}{dP} < 0$ it is seen that the pressure always decreases in an accelerating flow and increases in decelerating flow [6, 7].

Using this result

- For subsonic speeds M<1

  $\frac{dA}{dP} > 0$; $\frac{dA}{dV} < 0$

- For supersonic speeds M> 1

  $\frac{dA}{dP} < 0$; $\frac{dA}{dV} > 0$

- For sonic speeds(M= 1)

  $\frac{dA}{dP} = 0$; $\frac{dA}{dV} = 0$

The possible types of flow are summarized in figure (2)

The relations between pressure, temperature and density for isentropic process of an ideal gas are

$\frac{P}{P_o} = (\frac{\rho}{\rho_o})^{\gamma}$ $\frac{T}{T_o} = (\frac{P}{P_o})^{\frac{\gamma-1}{\gamma}}$ ………… (9)

Where $\gamma = \frac{C_p}{C_v}$

$$\frac{P}{\rho T} = \frac{P_o}{\rho_o T_o} = R \quad ....(10)$$

The temperature, pressure and density ratios as functions of Mach number yields the important relations[2]:-

$$\frac{T_o}{T} = 1 + \frac{\gamma - 1}{2} M^2 \quad ....(11)$$

$$\frac{P_o}{P} = (1 + \frac{\gamma - 1}{2} M^2)^{\frac{\gamma}{\gamma - 1}} \quad ....(12)$$

$$\frac{\rho_o}{\rho} = (1 + \frac{\gamma - 1}{2} M^2)^{\frac{1}{\gamma - 1}} \quad .... (13)$$

2-Experimental work

The system used in this work consists of three chambers. Each one was evacuated to different values of pressure by using different types of vacuum pumps to obtain the pressure gradient from (10^{-3} mbar in chamber one to 10^{-9}mbar in chamber three).

The source of molecular beam was fixed in front of the first chamber and we could move it along the system axis to reach the best position at which the shock waves can be decreased.

The second chamber was joined with the first one by the gas nozzle while the skimmer unit was used to transform the gas to the third chamber.

Figure (3) shows the main a part of molecular beam system and figure (4) shows the method used to fix the nozzle and skimmer in the system.

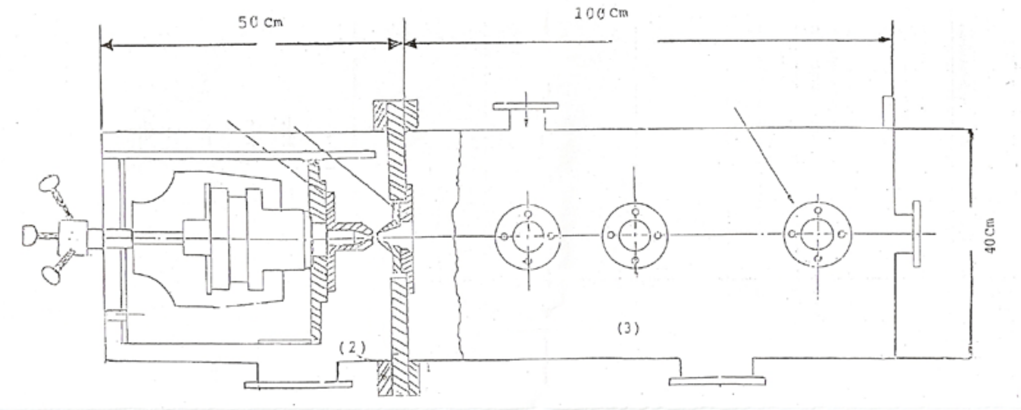


Figure (3) illustrated the molecular beam system

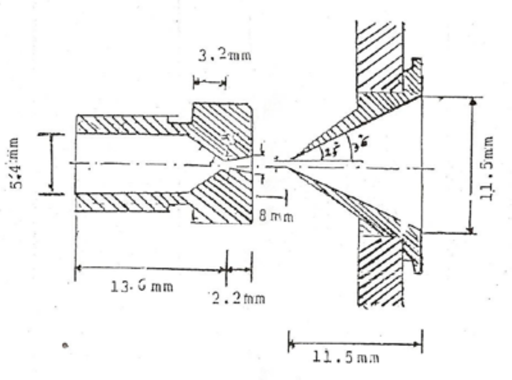


Figure (4) illustrated the main two parts nozzle and skimmer

3-Results

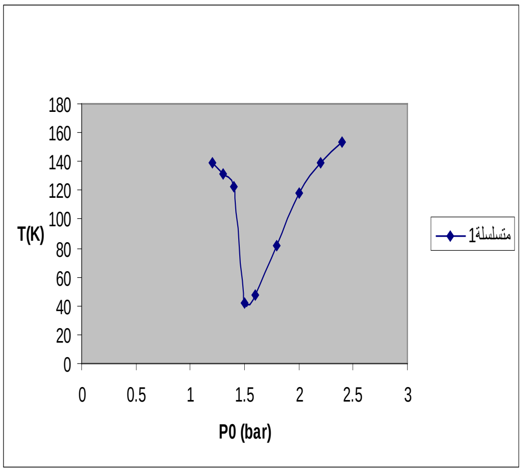
3.1 Measure of argon gas speed:-

When the argon gas injected in molecular beam chamber the ionization gauges responded to the gas particles and registered the difference between two signals coming from two gauges. Gas speed can be calculated since the distance between gauges is known.

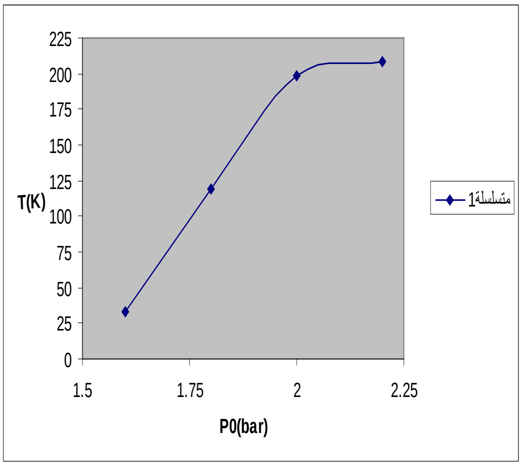
The second step was devoted to study the relation between the stagnation pressure of gas and other parameters which were measured by the gauges such as speed or temperature of the gas that was calculated theoretically from previous parameters (speed of gas) figure (5) shows this relation.

3.2 Argon and sulfur hexafluoride speed measurements

In this step the relation between the gas mixture speed and the stagnation pressure with were studied fixed value of argon pressure (1.5 bar).
The aim of this step is to obtain the best value of mixing ratio corresponding to the highest value of mixture speed and minimum value of temperature. Figure (6) shows that.



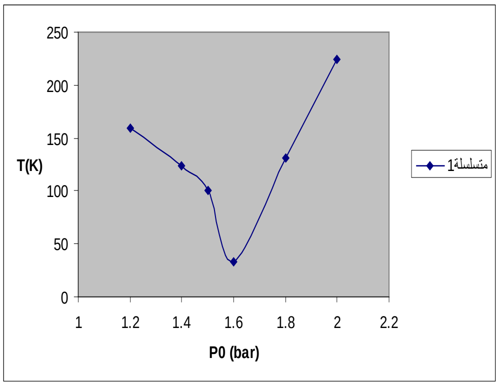
Fig(5) The stagnation pressure versus temperature degree of (Ar)



Fig(6) The stagnation pressure versus temperature degree of (Sf_6)

3.3Argon and sulfur hexafluoride at fixed mixing ratio measurement :-

This step also was concentrated to study the same relations such as in previous step. The relation between the stagnation pressure values to determine the minimum value of temperature was obtained by adiabatic expansion in molecular beam system. Figure (7) shows this relation.



Fig(7) The stagnation pressure versus temperature degree of(Sf_6+Ar) mixture

4-Conclusion and discussion

The aim of this research is to obtain the minimum gas temperature degree without condensation. From this work, we concluded that the best value of gas speed was obtained when we used the mixture gas (Ar + Sf_6) , (Ar was used here as a carrier gas).

The speed of gas is increased when the stagnation pressure increased until reaches the specific value. This value correspond to the point at which the shock waves takes place .When the speed of gas decreases the temperature will be increaseing after this situation .

5-References

[1]. Gordon J.Van Wylan , Richard E.Sonnty . (Fundamental of classical thermodynamic)3rd edition (1985)
[2]. Ascher H.Shapiro . (The dynamics and thermodynamic of compressible fluid flow. Ronald press company (New York) (1953)
[3]. Howarth.L. (modern development in fluid dynamics high speed flow .Oxford . (1963)
[4]. E.Borsella, R.Fantoni, A.Giardm ,A.Polucci ,J.Reuss and A.Zeeca. A Versatile molecular beam apparatus for multiphoton excitation . Studieds .C.P.56-0044. Italy 82,6 (1982).
[5]. Hakuro .Oguchi (Rarefied gas dynamics .2,Tokyo press (1984).
[6]. W.Ronald Gentry (Atomic and molecular beam methods),Tokyo (1984)
[7]. W.Kang,Eun.Kim and K.Jung (Time resolved molecular beam characteristic in pulsed supersonic),Bul Korean chem.Vol.16,No.3(1995).