A Gas Lens Using Unlike, Counter-Flowing Gases

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(Manuscript received May 26, 1964)

Because of the current interest in gas lenses for possibe use in long-distance laser beam transmission, it seems worthwhile to report on the successful operation of an example of another class of gas lenses. This class of lenses utilizes the difference of specific refractive index of different gases to achieve focusing in a region where there is a variation in relative concentration of different gases. In the device to be described, two gases flow together continuously from opposing tubes into a mixing chamber. The chamber is designed so that the effective interface where the gases meet is an axially symmetric curved surface, which acts as a lens for light passing down the axis of the opposing tubes.

In order to minimize distortion due to gravitational force, it is desirable to use two gases of about the same density. It may be most economical to separate and recycle the gases after they have run together. In principle, continuous separation with a semipermeable membrane would consume only a moderate amount of power. Except for a computation of the theoretical minimum of power consumption, no further discussion of the problem of gas separation will be presented in this paper.

A working model of a single element of a counter-flowing gas lens is shown in Fig. 1. Rather elaborate precautions were taken to avoid

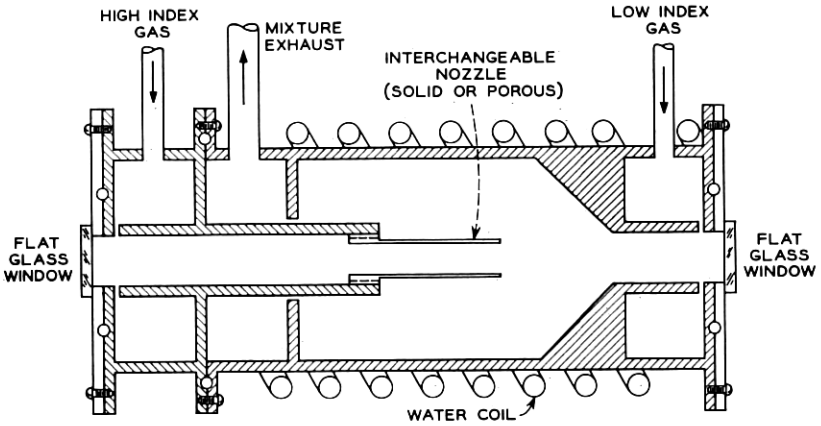

Fig. 1 — Experimental model of counter-flowing, unlike gas lens; over-all length is 8 inches.

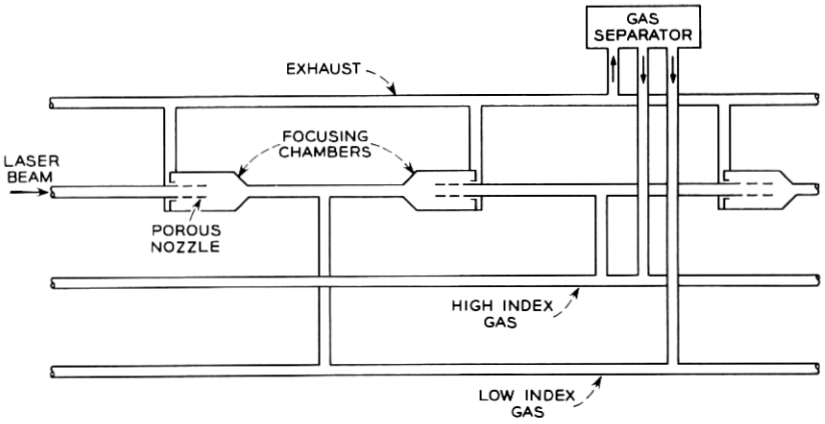

Fig. 2 — Schematic diagram of a part of a continuous series of counter-flowing, unlike gas lenses connected to a separator for recycling gases.

turbulence or asymmetry that might be introduced if the gas entered directly into the tubes through holes in the walls. Such precautions could probably be dropped if greater length of tubes existed between the points at which the gases enter and the regions in which they mix (see Fig. 2). For a continuous series of such lenses, one might have the actual lenses or "mixing chambers" a few feet apart, with gases of alternate types entering midway between the mixing chambers, as shown in Fig. 2.

The focal length and aberration of the lens as a function of flow rates were measured using a modification of the Foucault knife-edge test mentioned in the accompanying B.S.T.J. Brief on thermal gas lenses.[1] The two gases were run through long parallel copper tubes, which had been soldered together, before they entered the gas lens. Water was circulated through a tube soldered to the copper gas tubes and through a tubular coil wrapped around the gas lens (see Fig. 1). This precaution insured the absence of any focusing due to thermal differences. At moderate flow rates no appreciable aberration was observed, but some spherical aberration appeared before turbulence set in.

Fig. 3 is a graph of the variation of focal length with rates of flow of argon and CO_2. The lower group of curves shows such variation in the simplest model, in which CO_2 flowed out the end of a $\frac{3}{8}$-inch ID tube or nozzle into a relatively large cavity surrounding the end of the nozzle. The cavity was supplied with argon from the opening opposite the nozzle. The upper group of curves shows the same parameters when the solid nozzle was replaced with a cylindrical tube of 50-mesh copper screen. The screen allowed mixing of the CO_2 with argon over a longer distance with greater radial variation in concentration. The result is

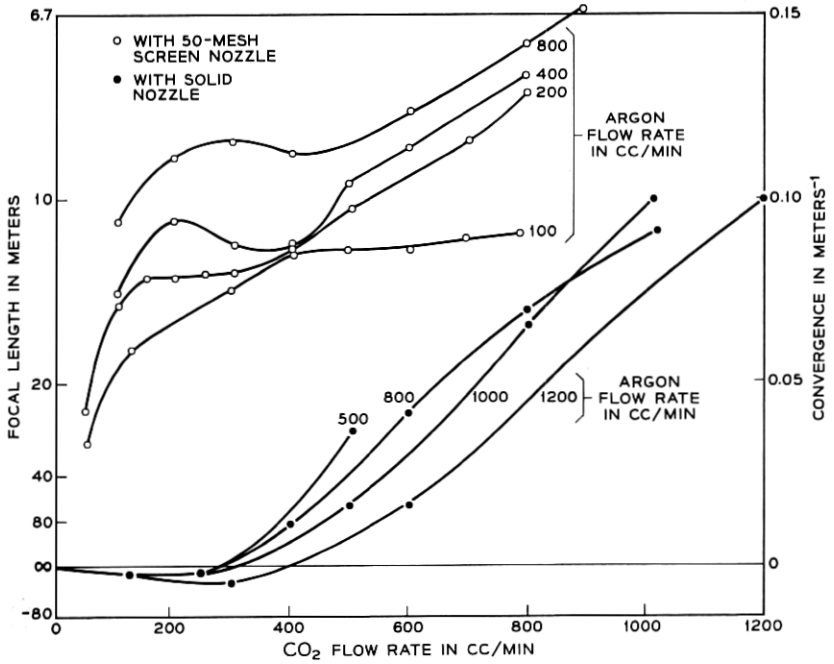

Fig. 3 — Graph showing variation of focal length and convergence with gas flow rates. Note increased efficiency using screen nozzle.

much greater curvature of the effective interface between the CO_2 and the argon, which gave a much shorter focal length at a given flow rate. Diffusion is certainly very important in the enhancement of focusing strength when the screen is used. A. R. Hutson was the first to suggest gas lenses utilizing refractive index gradients controlled by diffusion of gases of unequal refractive index into one another (private discussions with the author).

The curves stop at flow rates of about 1 liter per second of either gas because turbulence appeared at higher flow rates. Flow appeared to be completely free of turbulence at lesser flow rates.

The minimum power consumption, if the gases must be recycled, can be obtained using a simple thermodynamic argument due to K. B. McAfee.[2] If it were possible to find two semipermeable membranes, one for one gas and one for the other, the power required to separate the gases reversibly, neglecting small departures from ideal gas properties, would be

$$P = -fRT\left[\ln X + \frac{1 - X}{X}\ln (1 - X)\right]$$

where f is the flow rate of one of the gases in moles per second, R is the gas constant in joules/mole °K, T is the absolute temperature, and X is the mole fraction of that gas in the mixture. If the flow rate of each gas is 200 cc/minute, so that $X = 0.5$, the formula gives a power consumption

$$P = 0.50 \text{ watts.}$$

Tests showed that the focal length at such a flow rate was about 15 meters in the lens with a screen nozzle, using CO_2 and argon. The theoretical maximum "efficiency" of the lens is thus 0.13 diopters per watt at this flow rate. It may be of interest to note that this efficiency is the same order of magnitude as that of the convective helical gas lens reported in Ref. 2. However, it should be emphasized that such low power consumption is only a theoretical limit for a counter-flowing gas lens of these particular dimensions.

Acknowledgments. It is a pleasure to acknowledge many helpful discussions and much encouragement given by A. R. Hutson in the course of this work. D. E. Collins has been of great help in setting up and performing the experiments.

REFERENCES

1. Berreman, D. W., A Lens or Light Guide Using Convectively Distorted Thermal Gradients in Gases, B.S.T.J., this issue, p. 1469.
2. McAfee, K. B., Diffusion Separation, *Encyclopedia of Chemical Technology*, Suppl. 2, Interscience, New York, 1960, p. 297ff [the formula presented here comes from Eq. (13)].