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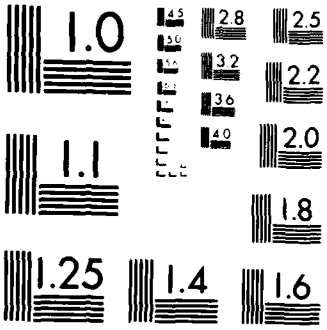

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An investigation of interfacial turbulence at gas-gas interfaces is reported.

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Abstract

A Study of Interfacial turbulence at interfaces formed by different phases is becoming increasingly important in transport effects across such interfaces, which impinge directly on the Engineering Sciences, hence technology and the military.

All interfaces cannot be treated in the same theoretical or experimental frame-work since, the mathematics governing the motion of the different phases is different and the physical properties of gas and liquid phases are different, necessitating different experimental techniques. For example, the gas-gas interface would not fall under the same considerations of gas-liquid or liquid-liquid, which accounts for the sparsely available literature on the subject, enhancing the difficulty of the contemplated problem.

In this case also, with a gas-gas interface in turbulent motion we have free turbulence, as it is not being influenced by a solid boundary, but unlike the physical situation of jets emitted into stagnant or slowly moving fluid or slower moving lfuid, where the rate of spreading in the flow direction is important.

Here, the rate of mixing of each gas with the other across the interface is important, an interface that is not necessarily clearly defined, but can assume any of the three possibilities, spherical, cylindrical or planar at various positions of the interface as the containing, sobering and smoothing effect of surface tension no longer prevails or exists.

The problem also resolves itself into various transport coefficients, microscopic and macroscopic depending on whether each phase is treated as a continuum or not and which dependes on the kind of flow established sub-sonic, super-sonic or hyper-sonic, all of which depend on the value of the mach number, $M = \frac{V}{a}$.

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Approach

In the previous cases of interfaces formed from gas-liquid, liquid-liquid, a clearly defined planar interface existed due to surface tension effects. Here, however, this not the case, nertheless, we can imagine a thin planar membrane separating the two gases which are agitated and then released quickly, so that initially, there is a planar interface existing between the two gases.

Obviously, molecular diffusion will commence at the interface whether it is agitated or not. However, there are several possible approaches to the problem depending on the type of flow envisaged, where-by the fluids are treated as continuum or not.

Whether we treat the medium as a continuum or not would imply two approaches:

1. The continuum approach, where the equations of continuity, momentum, and thermodynamics (energy relations) are considered, which are elliptic and hyperbolic and cannot be solved exactly by known mathematical theories. However, models can be formulated with physical and mathematical insights and approximations, thereby simplifying the problem and making it more tractable, either for a direct solution or numerical analysis. Here, again, phenomenological theories may be applied.

In this cases, the flow conditions become important and two kinds of transport coefficients exist. Those that are fluid properties on a microscopic basis and those that are macroscopic effects, not properties of the fluid and depend on the flow characteristics.

2. If, however, the medium is treated on a purely statistical basis from the particle point of view, then we are dealing with the dynamics of collinding particles. Here, again, transport coefficients are properties of the fluid on a microscopic basis, leading to free molecular flow theory, as for rarefied gases.

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We envisage different kinds of transport across the interface, molecular, eddy large scale fluctuations with entrainment and large scale convection eddy transport. Again, depending on the flow visualization and the predominance of some over others an assessment of mixing would be effected and its dependence on turbulent parameters determined.

We shall deal first of all with the phenomenological approach to the problem and we envisage certain similarities in the established flow pattern by the mechanical agitators (stirrers), as with liquid phases.

For a single phase system where one gas is agitated by contra-rotators, a turbulent core is envisaged in the immediate neighbourhood of the stirrer assembly with an irrotational super-layer, similar to the re-entry of rocket motion, depending on the stirrer speeds.

However, there is no plane interface as those formed by liquids but a contorted corrugated boundary forming the gas-gas interface, which is not static but dynamic, as it constantly changes it's shape, form and position. We visualize regions where dynamic equilibrium is established by equating the eddy pressures on both sides, so that $\rho_1 u_1^2 = \rho_2 u_2^2$, which are temporarily static, while other regions are live and dynamic. These temporarily static regions of interface become dynamic, when eddies are replaced by others impelled from the bulk phase or collapse back into its original phase, making certain regions of the interface intermittently static and dynamic.

The attraction between eddies in liquids and the interaction between them, both physically and inertia-wise are much stronger than in the gas phase, where eddies are more volatile and can break away from the bulk phase completely, leading to convective eddy transport.

In mixing of free turbulent jets, like liquid jets into gases, the bulges on the periphery of the liquid due to eddy manifestations are contained and damped by surface tension forces, which do not prevail at gas-gas interfaces, enhancing the possibility of convective eddy transport.

Again, in the case of free turbulent jets mixing occurs in three ways, as follows:

1) Entrainment, caused by appreciable eddying on the outer regions (periphery) of the jet, since the velocity does not die out to zero abruptly, as in the case of a solid wall.

2) Turbulent Diffusion, governed by the eddy mixing length within the jet at any point.

3) General circulation, caused or established in the surrounding fluid by induction.

If turbulence is established in a region of a fluid entrainment of the ambient or quiescent medium takes place in three ways as follows: See reference (15).

1) Induction

2) Disatrophy

3) Infusion

All of this takes place in the same medium.

In the problem contemplated here, mixing across a gas-gas interface can occur in four ways, as follows:

1) Ordinary Molecular Diffusion or transport is always present, static or dynamic interface and is proportional to $D^{1/2}$,which is small

2) Surface renewal of eddies in dynamic equilibrium, where $\rho_1 u_1^2 = \rho_2 u_2^2$, which are replaced by eddies impelled from the bulk phase, as in the previous cases discussed with liquid interfaces, leading to molecular diffusion, proportional to $D^{1/2} N^{1.3}$, where N is the stirring speed, hence synonymous with Reynolds number or degree of agitation. This effect, supersedes ordinary molecular diffusion, but nevertheless small.

3) Entrainment of the upper phase into the lower phase by the appreciable dynamic eddying at the interface, where these contorted and corrugated regions collapse or turn back into themselves, the original phase, entraining or physically trapping a volume of fluid comparable to its own size. The rate of mixing per unit area = $\frac{\text{mass X frequency}}{\text{area}}$ $= \frac{\varrho \lambda^3}{\lambda^2} f = \varrho \lambda f = \varrho v$, using the wave concept for eddies of size λ over the corresponding wave numbers. v, here, is a characteristic eddy velocity, which can be equated to the mechanical stirrer establishing the turbulence, hence $v = NL$, where N = stirrer speed and L = length of stirrer, implying that mass transfer due to entrainment is proportional to (ϱNL), which suppersedes and predominates over the two previous effects

4) Convective transport, which is inevitably due to the volatile nature of gases and the absence of the smoothing, sobering and containing effect of surface tension from the lower phase to the upper can also be viewed as entrainment of the lower phase by the upper phase. Mathematically, we have at any across-sectional area A, of eddy convective motion across the interface; $\varrho v A$ = rate of flow of matter, hence rate of transport per unit area = ϱv, same order at magnitude as effect (3) and can be considered as a special case.

Conclusion The total rate of mixing at a gas-gas interface is proportional to ϱv which is proportional to ($\varrho N L$).

We may extend the problem to the case where both phases are agitated, all the previous forms of transport processes would occur, hence the total rate of mixing at a gas-gas interface is proportional to ($\varrho_1 N_1 L_1 + \varrho_2 N_2 L_2$) as the predominant factor.

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