DYNAMICS DAYS SOUTH AMERICA 2010
International Conference on Chaos and Nonlinear Dynamics

INPE – National Institute for Space Research
São José dos Campos – SP – Brazil – July 26-30, 2010

ENTRAINMENT AND MIXING IN FOUNTAINS IN STRATIFIED MEDIA

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We present experimental results about the interaction between turbulent fountains and stratified media. When a fluid is injected in a linear stratified fluid with density smaller than that of the jet, firstly, the jet reaches a maximal height, and then, due to the effects of mixing and friction this height is stabilized at certain value. The upward flow not only reduces its momentum but also entrains environmental fluid reducing its density to an intermediate value and forming a front of cold fluid which intrudes horizontally on the environment. Using visualization and velocimetry techniques we find that the maximum and intrusion heights depend on the turbulent fluctuations of the jet and the effect of high levels of turbulence is to reduce these heights. We study quantitatively the mixing and entrainment between the jet and environment.
keywords: Turbulent Fountain, Stratified media, Mixing

Frosts are a problem of worldwide importance, because their affects significantly agriculture and food production. Generally speaking, frosts are grouped into two types of phenomena called advection and radiation frosts. On the one hand, advection frosts are the result of the passage of polar, very cool and dry, air over a delimited place. Their effects are devastating, however, they are, fortunately, extremely infrequent in temperate regions. On the other hand, radiation frosts occur by night in winter and spring, when the sky is clear (without clouds) and there is no breeze. This scenery is repeated several times throughout the year in temperate regions, causing damages that due to their frequency, result in a considerable economic loss.

Under radiation frost conditions, the surface cools by radiation through the atmosphere. Cooling is more marked in the lower layers of the atmosphere (first tens of meters) and decreases as we ascend in the atmosphere. Under these conditions, in the atmosphere near the surface we have the so-called "thermal inversion", since, contrarily to what happens during the day when air temperature decreases with altitude, in radiation frost air temperature increases with altitude in the lower layers. As air density increases with temperature, the atmosphere becomes stabilized as the lower layers are the coldest and therefore the densest ones.

There a several strategies, like the installation of heaters, sprinklers, and, even, the use of helicopters, in order to control the damages due to radiation frosts. All of those solutions have serious withdraws. Another device, namely SIS (Selective Inverted Sink), which has same years in the market (see www.frostprotection.com), operates on the stratified atmosphere performing selective withdrawal of the denser layer of the air (colder layers). This device adds mechanical power in order to impulse upwards a jet of cold air. This jet carries not only the fluid that the device expels but also entrains or captures fluid in the horizontal layer it runs through.

In this work we study a laboratory model of the SIS in order to understand its basic mechanisms and, also, to propose improvements to its design. Our model consist of a turbulent fountain, usually defined as a jet in which, as a result of a difference between the density of the fluid jet and the environment[1–4], the buoyancy force is acting in the opposite direction of the jet. In the laboratory, fountains are produced by injecting dense fluid upwards through a nozzle placed at the base or top of a tank. The whole fluid in the container present a stable stratification and has a density less than or equal to the source fluid. The environmental fluid is entrained into the initial upflow, increasing the fountain radius and decreasing the source fluid density. The momentum of the rising fluid is reduced by the opposing buoyancy force until the flow first comes to rest at an initial height above the source.

The downflow which forms after this point continues to mix with the environment while also interacting turbulently with the upflow restricts the rise of further fluid and therefore reduces the initial fountain height to a final value [1]. The final density of the downflow presents a strong dependence of the strength of the ambient stratification. In this work, we give a detailed description of the flow inside the jet, obtained with PIV technique. In Fig. 1 four snapshots of the initial evolution of the fountain are shown.

The experimental setup consists of a prismatic recipient with lateral isolated walls and bottom and top walls made of aluminium sheets with controlled temperature. The fluid within the container is water linearly stratified in height with the boundary conditions of 15°C at bottom and 40°C at the top. In order of getting such stratification, we heated carefully different intermediate layers of water by using a sliding resistance. Various thermocouples helped us to monitor the temperature of the different water layers.

The jet is injected at $15°C$ from an $8,0$ mm diameter circular nozzle at the centre of the bottom base of the recipient. Different degrees of turbulence are generated in jet by means of various stainless steel woven wire grids placed at the inlet of the recipient. In order to measure the velocity field, we use the well-known technique DPIV (Digital Particle Image Velocimetry). In the present work we characterize the turbulence intensity by applying this technique in a small area immediately over the jet inlet. We use a dye technique in order to analyze the whole motion of the fluid and visualized the intrusion. A color map of the standard deviations of the vertical component of the velocity (the most significant component) over the capture region is shown in Fig. 2.

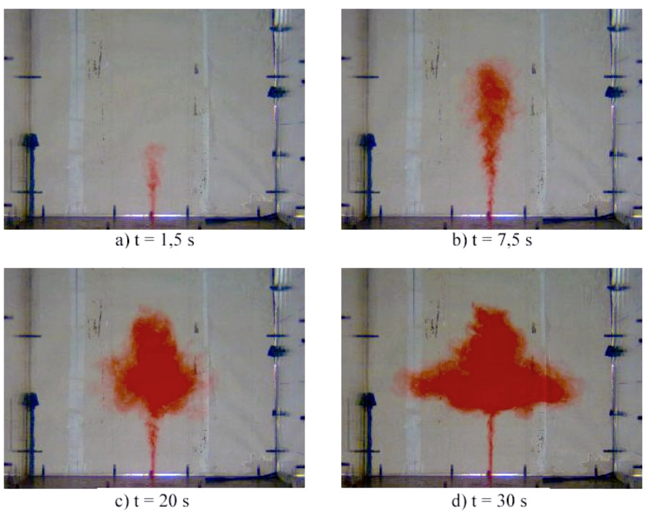

Figure 1 – Images of the jet evolution. a) the jet has just started to be injected; b) the jet is about reaching the maximum height; c) denser fluid started to fall; d) jet fluid is accumulating at an intermediate height and spreads laterally.

We quantitatively study the dependence of the maximal and intrusion height with different parameters of the flow, in particular with the turbulent fluctuations. From our results, we conclude that the higher is the turbulence, the lower is the maximum and intrusion height reached by the jet. We also present quantitative results for the entrainment and mixing. This study suggests that turbulence generation could affect the efficiency of systems like the SIS. A possible solution to improve the system could be the inclusion of stationary or rotating blades, or some other mechanical device in order to decrease the jet turbulence, and then diminish the power needed by the machinery without affecting its actual performance. This work, which is still in progress, can contribute to improve a specific device which has important economic implications.

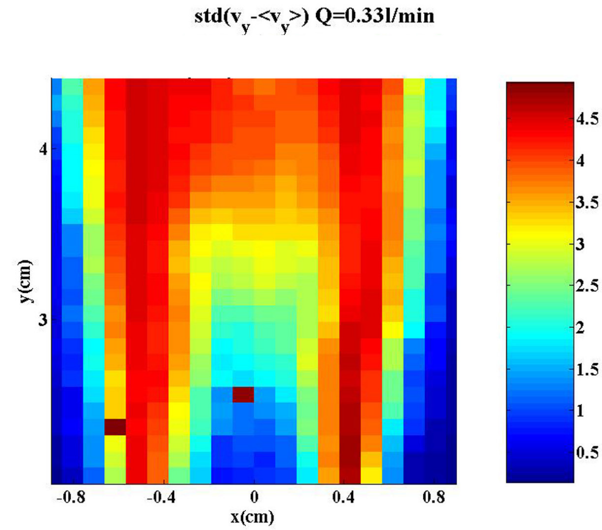

Figure 2 – Standard deviation of the velocity vertical component

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