Thermodynamic Availability Sources from Inertial Energy. Cooling Mechanisms.

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ABSTRACT

Research and experimental tests in the development of new cooling mechanisms for gas turbines rotor disks and blades, are described. A new high heat transfer cooling system physical configuration, utilizing rotating ducts (pipes) filled with a liquid in a pressurized hydrostatic condition (no fluid flow, no coriolis effects) was designed and tested. Phenomenological experimental observations confirmed, that a generalized mixing (mass transfer) and an axial momentum exchange in the liquid particles, were originated by inertial forcing. Conservation laws and subsidiary equations applied to the liquid mass, indicate, that a centrifugal potential energy unbalance and periodic body forces work, originate these reactions in the liquid, as the physical (pipes) and hydrostatic (incompressible fluid) boundary conditions do not permit any other result. Inertial energy dissipation and work, originate an irreversible process with entropy generation, which is used to create high heat transfer coefficients in this liquid cooling system.

Keywords: gas turbines, cooling, efficiency, nanofluids, heat transfer.

1 INTRODUCTION.

Many new Distributed Generation (DG) investment projects, with shaft-power needs in a very specific range (Smart-Grid DG logistics optimization), present new particular operational and economical requirements to be technically feasible and financially viable (ROI).

Furthermore, new enhanced co-generation applications and Combined Heat and Power (CHP) processes, will require sources (disposable mass flows) of higher quality heat (increased pressures and temperatures) to obtain new levels of overall energy efficiency and environmental impact control.

New industrial (non-aeroderivative) gas turbines (shaft-power), integrating innovative conceptual designs and a updated product engineering, with increased rotors disks and blades cooling capabilities, will satisfy those new requirements in energy efficient equipment and environmental engineering (E5) advanced cleantech applications.

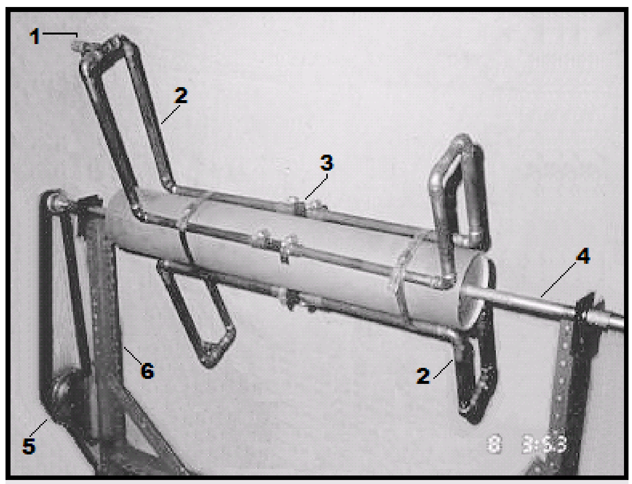
Higher gas turbine rotors inlet temperatures, will permit not only an increase in the gas turbines cycle efficiency, but also, to have higher quality heat sources in the exhaust gases mass flows, with surplus pressures and temperatures available for enhanced co-generation applications and improved energy management and optimization strategies in combined heat and power processes.

2 TEST APPARATUS.

The test apparatus physical configuration, shown in the photograph of Figure 1, was developed by analysis of the cooling liquid boundary and hydrostatic conditions, the characteristic axial and radial dimensions, pipes diameters, and the operation parameters, with numerical simulations including the inertial effects magnitudes and all the variables involved gradients and distributions in a no-flow condition.

2.1 Components description.

The general description of components presented in Figure 1, include two closed loops formed with pipes (the lower identical loop was installed only for balancing purposes during the rotation tests), symmetrical loops including transparent sections for the experimental visual observations planned. The data correspond to the apparatus configuration described in Figure 2.



1 - FILLING DUCT (HEAT TRANSFER LIQUID) AND TIGHTENED CAP (LIQUID PRESSURE).
2 - LOOPS (PIPES).
3 - TRANSPARENT SECTIONS.
4 - ROTATION AXIS (HORIZONTAL).
5 - ROTATION VELOCITY PULLEYS AND BELT BAND.
6 - SUPPORT STRUCTURE.
DATA: R3 = 43 CMS. R2 = 27 CMS. L = 63 CMS. W = 8 CMS. R1 = 5 CMS.

Figure 1: Test Apparatus.

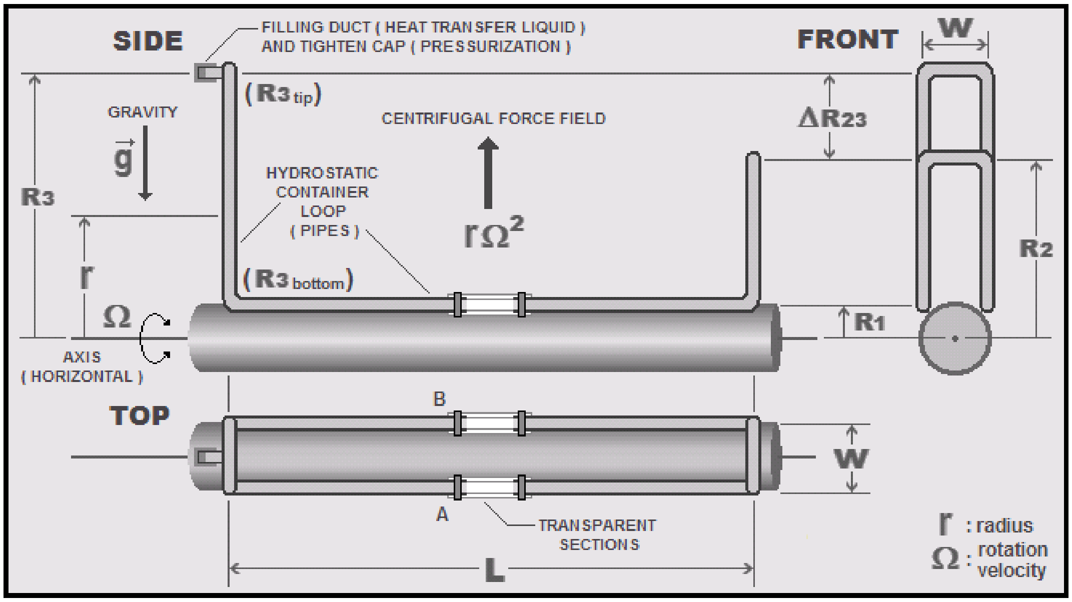


Figure 2 : Test Apparatus. Configuration.

2.2 Inertial cooling system configuration.

Figure 2 shows, the geometric design and operation variables for the apparatus (figure 1) used in the experimental tests, representing an inertial cooling system prototype configuration to be installed in a gas turbine, as it is shown in figure 3, which corresponds to a industrial gas turbine model with a vertical combustion chamber [1].

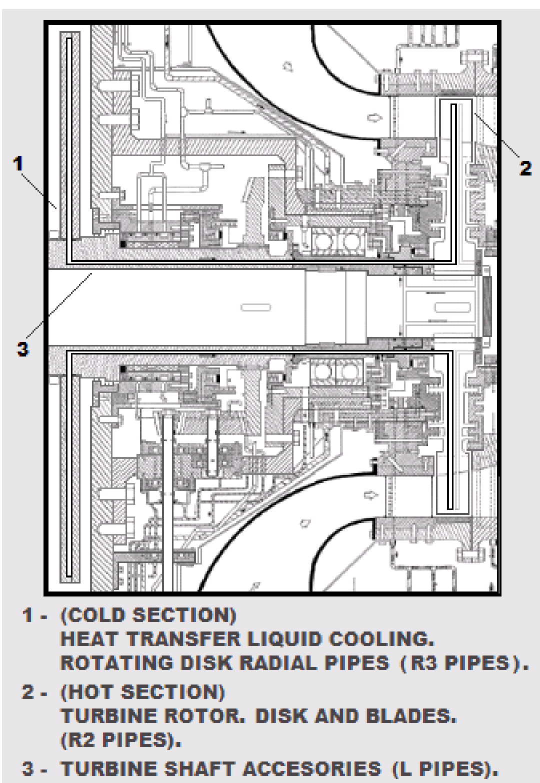


Figure 3: Cooling system. Gas turbine installation.

3 PHENOMENOLOGICAL OBSERVATIONS. TESTS.

Two sets of experimental tests were performed on the apparatus, each with different observation objectives.

3.1 Tests preparation. Liquid initial condition.

- The installed pipes loops (both), were filled in the vertical position with a liquid (water at Tamb) through the filling duct. Air was eliminated and the liquid was pressurized (Po) tightening the cap. - The liquid mass was pressurized and had a fixed volume (pipes volume), having no free surface or any other means to deform or change shape within the pipes loops. - In this way, a totally hydrostatic, fixed volume, incompressible fluid, pressurized physical initial condition, was applied to the liquid mass.

3.2 Considerations.

- In the rotation tests (horizontal axis), no existing pressure gradient can originate a fluid flow for these physical boundary conditions (even in this loop pipes arrangement, as gradients are symmetrical and cancel out in sides A and B of the loop). - Without a fluid flow (no liquid velocity in the rotation non-inertial frame), no coriolis effects exist. - The hydraulic initial conditions during the rotation tests, remained totally hydrostatic, under the only acting inertial fields: gravitational and centrifugal. - In these tests no external temperature gradients, axial or radial, were applied to the rotating apparatus (cold tests).

3.3 Tests set 1: Powder colorant in liquid.

A) At the initial condition preparation, before tightening the cap and pressurizing to Po, a powder colorant quantity was added to the liquid at the filling duct position (R3tip in figure 2). **B)** The apparatus was rotated at different velocities and results were observed at different times. **C)** Been R3tip, the point of maximum hydrostatic pressure on the rotation tests due to the centrifugal field, even under these totally hydrostatic conditions, no powder colorant depositing or sedimentation originated at this point. **D)** At different test times, an advancing colored liquid front was observed (transparent sections) in the direction shown in figure 4 (from R3 to R2).

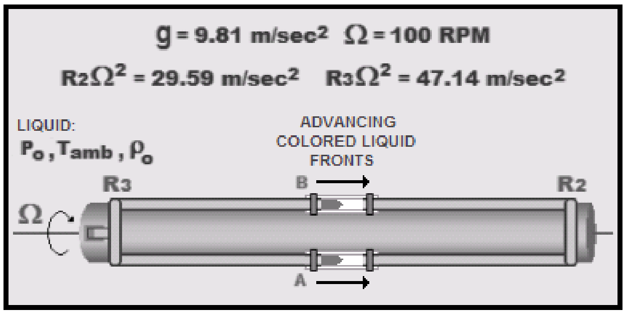


Figure 4 : Generalized Mixing. Mass Transfer.

At higher rotation velocities, this colored front was observed passing in shorter times. **E)** Eventually, all the liquid mass acquired a steady uniform lighter coloration. Although the fluid condition was totally hydrostatic even in the non-inertial reference frame, without surface work done on the liquid (stirring), a generalized mixing in the fluid particles or mass transfer process, was present. **F)** Without a fluid flow, there is no boundary layer, and neither this can be analyzed strictly as turbulence. This steady mass transfer process was originated by a hydrostatic (molecular) mixing activity. **G)** The mixing energy received by the liquid mass had an inertial (rotation) origin. Due to the physical and hydrostatic boundary conditions, this (molecular) mass transfer without convection (no fluid flow) was the only physical reaction possible.

3.4 Tests set 2: Solid spherical objects.

A) At the initial condition preparation, again, before tightening the cap and pressurizing the system to Po, four solid spherical (colored) objects, planned (material and volume) to have positive flotation in this liquid (water) under the acceleration of gravity only, were deposited in the liquid mass on the filling duct position (R3tip). **B)** In the rotation tests, under these hydrostatic and physical boundary conditions, the four solid objects (discrete mass each), should have moved only to the R3bottom position (figure 2) and remained there steadily, as they had positive flotation in this liquid also under the centrifugal acceleration field. **C)** On different tests and times, the four solid objects were observed (object's color) to randomly take one side or another (A or B) of the loop moving axially in the direction shown in figure 5.

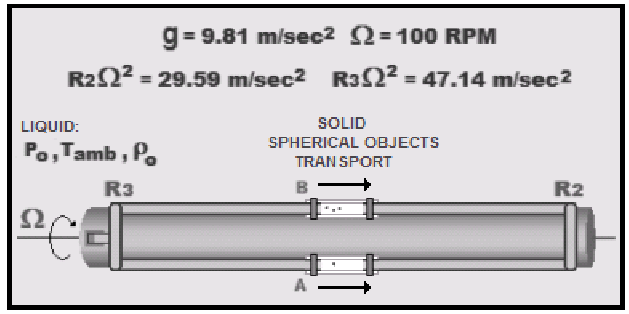


Figure 5 : Axial Momentum Exchange.

D) Without liquid flow in the pipes, these solid objects (discrete mass) axial motion indicates, that there is also, a macroscopic axial momentum exhange in the liquid particles which physically transports axially the solid objects (without a fluid flow). **E)** At higher rotation velocities, the objects axial movement observed was faster (increased transport), and this directional momentum transfer had to be originated by inertial effects.

3.5 Tests analyses. Conclusions.

1) All the tests showed, that the generalized (molecular) mixing and the (macroscopic) axial momentum exchange in the liquid, are strongly dependent on the rotation velocity, an so, must have an inertial origin.

2) Conservation laws and subsidiary equations applied to the rotating liquid mass (closed thermodynamic system), indicate, that although no surface work is crossing its boundaries (control volume), energy is been transferred to the liquid, and due to the physical and hydraulic boundary conditions, that energy has to be irreversibly dissipated within the system as increased entropy in the liquid, dissipation which originates these thermodynamic or physical reactions in the rotating liquid mass.

3) The liquid initial internal energy (Po, Tamb) was a magnification factor for the intensity of the liquid reactions observed. Increasing the initial liquid pressurization Po, originated a stronger mixing and momentum exchange.

4) As it is a highly compressed liquid (high saturation temperature. no phase change), very high heat transfer coefficients can be obtained with this physical rotating arrangement, with the advantage of using a new high heat transfer nanoliquid, mechanically configuring the arrangement to be installed as a inertial cooling system in gas turbines with a external axial temperature gradient applied between the hot and cold sections.

4 ORIGIN OF THE LIQUID REACTIONS. INERTIAL FORCING.

The following are the two inertial forcing mechanisms:

4.1 Centrifugal potential energy axial gradient.

The total centrifugal potential energy of the liquid mass in this physical configuration of a (rotating) closed thermodynamic system, is unbalanced.

Figure 6 shows, that on R3, the excess liquid mass corresponding to the geometric design difference (R3-R2), originates the magnitude of this unbalance, and a total centrifugal energy axial gradient (along designed L) between R3 and R2 exists.

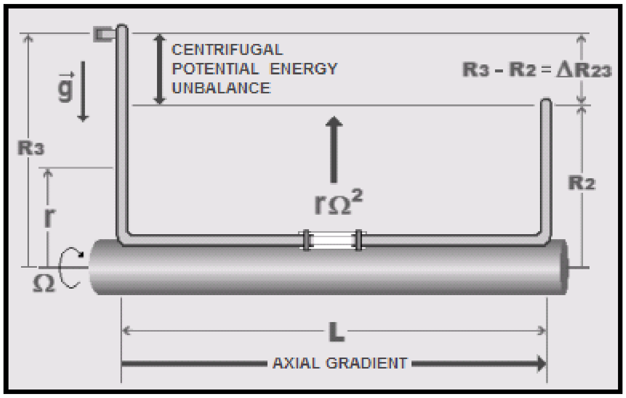


Figure 6 : Centrifugal Potential Energy Unbalance.

This centrifugal potential energy axial distribution imposed by design, is dissipated in the closed system, due to the physical boundary conditions (no fluid flow possible), not totally as an increase in the liquid internal energy (incompressible fluid. no temperature change), but as an irreversible steady process with an entropy increase, which originates the steady macroscopic directional momentum exchange observed in the axial direction, which transported the solid objects without a fluid flow.

4.2 Body forces periodic interaction.

The respective centrifugal acceleration radial distributions, of the liquid masses in the rotating radial pipes R2 and R3, have each, a periodic interaction with the constant gravity acceleration, as it is shown in figure 7.

The resultant inertial or body forces **Fi(r)** periodic radial gradients in each radial pipe, applied to the liquid mass, correspond to a inertial forcing or body forces work done on the liquid (mixing energy), which originates a steady generalized mixing or mass transfer process, as the physical and hydrostatic boundary conditions, here again, do not permit any other result.

As **Fi(r)** is different on radial pipes R2 and R3, a mixing intensity or molecular diffusion axial gradient also exists, which is imposed or is molecular pervasive, in the axial macroscopic momentum exchange observed.

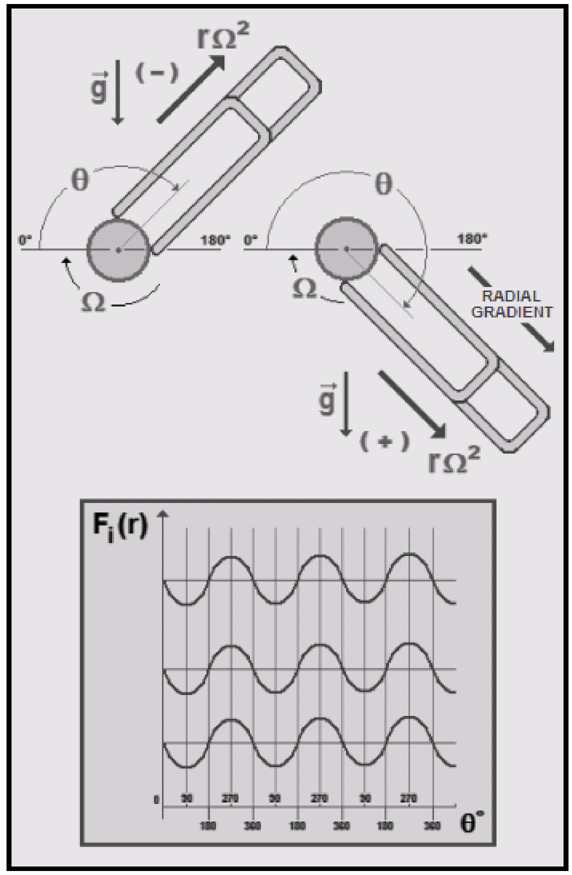


Figure 7 : Periodic Body Forces Interaction.

5 AXIAL TURBINE STAGE PROTOTYPE.

Experimental tests on an axial turbine stage prototype with a liquid inertial cooling system, have been performed,

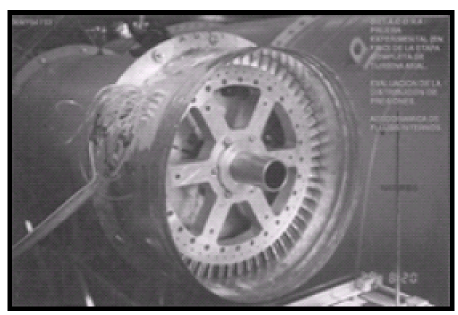


Figure 8 : Axial Turbine Stage Prototype.

and further development has been recommended (figure 8).

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