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AN ANALYSIS ON THE EFFICIENCY OF VANE TYPE DEMISTERS

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ABSTRACT

Some geothermal fields produce vapor with high concentrations of Hydrogen chloride. When it happens steam washing is necessary to prevent corrosion. Generally washing operations are performed using a caustic solution that is sprayed with a nozzle directly in the pipeline. If the vapor is superheated, part of the injected solution vaporizes to saturate the vapor phase and the rest has to be separated with a cyclones and/or Vane type demisters. This operation is entrainment of the liquid, that contains high concentrations of salts. This can be the cause of scaling and corrosion of the turbine. Finally, in this paper the performance of commercial vane type demisters has been experimentally analyzed.

INTRODUCTION

In high enthalpy geothermal fields the vapor is carried from the well-head to the power plat by insulated pipelines. If the insulation is absent or if it is damaged, temperature drops and condensation occurs. In geothermal steam, the presence of Hydrogen Chloride has been deeply investigated /1/, if it is present, it acidifies the consensated and corrosion is enhances. To prevent corrosion phenomenon if the Hydrogen Chloride concentration exceeds 15-20 ppm., it is a common practice to wash the vapor phase with a caustic soda solution. Conventional techniques of steam washing consists of an injection of caustic solution directly in the transport pipelines. If superheated steam is present, part of the injected solution evaporates, saturating the vapor phase. The remainder contains a high concentration of salt and has to be separated. The washing operation can be performed in different ways, for instance Macker and Haizlip/2/ suggest using multiple injection nozzles, whereas ENEL/3/ prefers to use a system containing static mixers. In both cases, a high efficiency of abatement can be obtained. Both of the systems must be followed by a separation stage that is generally composed of a cyclone and/or a vane type demister. Liquid separation is an operation of great importance, because if the efficiency of this stage is low, the vapor phase that flows to the turbine, entrains drops with a high concentration of salt. If this occurs, it may cause the deposition of salts and the corrosion of the turbine blades. Experimental data performed in Larderello area have showed that this deposit is essentially Halite that is derived from the chemical absorption of Hydrogen Chloride. To avoid the deposition of salt in the turbine, a careful design of the separation stage is necessary. The goal of this work is the evaluation of the efficiency of vane type demisters, for this reason a pilot plant has been designed and built.

DESCRIPTION OF THE EXPERIMENTAL LOOP AND TEST EXECUTION

A schematic diagram of the experimental loop is showed in figure 1. As can be seen, the pilot plant consists of a pipeline 4.5 meters long, with a rectangular cross section whose dimensions are 0.12 meters wide and 0.19 meters high. In this paper the separation of little drops of water carried from a high air flowrate has been studied.

The air is sucked by a fan that allows experimental data up to a maximum velocity of 25 m/s to be measured. The flowrate is measured by a set of removable flow nozzles, that have been built to obtain high accuracy in all ranges of air velocity and they are controlled by the valve that is located close to the fan.

The drops are produced by a specific ultrasonic nozzle that is needed to obtain a high concentration of drops with a diameter less than 10 um. This nozzle is supplied by a volummetric pump, for the liquid phase and by compressors that work up to 6 Bar for the gas phase.

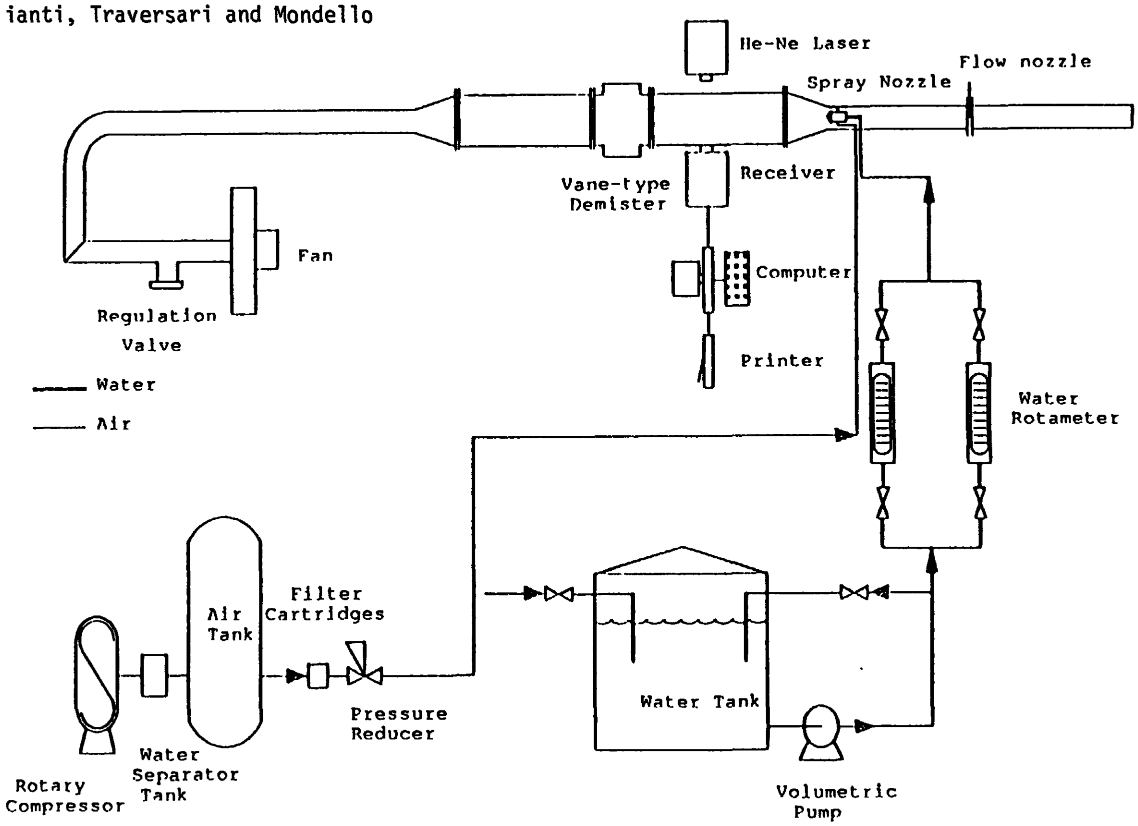

Fig. 1 Schematic diagram of experimental loop

The efficiency of the separator has been computed measuring the concentration of drops before and after the vane type demisters. To obtain this goal a Malvern Particle Sizer has been used. This instrument, besides total concentration measurement, subdivides the drops in 15 classes, according to the dimension, and for each class supplies volummetric concentration. This information is really important because it allows us to know how drop size influences separation efficiency.

ANALYSIS OF THE PHENOMENON

This type of separator is usually adopted in many applications but the design is generally performed using empirical equations. Inertial separators consist of simple plates mounted at a certain angle. The gas stream with entrained drops flows in the vane blades changing his path many times. The droplets cannot follow the gas stream because momentum and for this reason tend to impinge against the target blades, where they coalesce and successively are drained away as liquid film.

Many complex phenomena attend to the efficiency of the separator. One of these is the interaction between droplets and turbulence. To take into account this phenomenon, some authors /4/ simulated the behavior of this separator with the tool of software packings that allows the solution of the Navier-Stokes equations adapted to turbulent flows. The experimental results are not really significant because at high computation, complexity does not correspond to high accuracy in the efficiency prediction. For this reason, in this paper, a simplified analysis of the phenomenon is presented.

Starting from a balance force and neglecting the influence of the turbulence, it will be shown that the separation process is a function of dimensionless Stokes number.

The forces that work on the drops are:

- Drag Force
- Inertial Force
- Pressure Force
- Virtual mass force
- Gravity force
- Saffman lift
- Basset force

and other forces of minor importance. The problems seem to be complex but can be simplified because the forces have different weight.

In this work, horizontal separators are studied and in this configuration it is possible to neglect the influence of the gravity force. This assumption is justified from the observation that the falling velocity of the drops is negligible in respect to velocity of the gas.

Other forces, as Saffman lift an Basset term, can be neglected because the first one only acts in a high shear region of the gas flow, and the other one is important only if the gas viscosity is high.

If the ratio between the droplets and the gas density is in the order of 1000, as in this case, the pressure force and virtual mass force can be neglected so the momentum balance is reduced to

$$\frac{d\bar{U}_p}{dt} = \frac{3}{4}\cdot\frac{\rho_g}{\rho_l}\cdot\frac{C_d}{d_p}\cdot\left(\bar{U}_g - \bar{U}_p\right)\cdot\left|\bar{U}_g - \bar{U}_p\right| \qquad (1)$$

where Up Ug are the drop and the gas velocity, pg and pl are respectively the density of the gas and the liquid phase, dp the drop diameter, and Cd the friction factor.

Integrating Equation 1 it is possible to obtain droplet trajectories as

$$\tau\cdot\frac{d^2x}{dt^2} + \frac{dx}{dt} = U_g \qquad (2)$$

where

$$\tau = \frac{4}{3}\cdot\frac{\rho_l}{\rho_g}\cdot\frac{d_p}{C_d}\cdot\frac{1}{\left|\bar{U}_g - \bar{U}_p\right|} \qquad (3)$$

The equation (2) can be write in dimensionless form in the following way:

$$\dot{t} = t\cdot\frac{U_{g,x=0}}{L}$$

$$\dot{x} = \frac{x}{L} \qquad (4)$$

$$\dot{U}_g = \frac{U_g}{U_{g,x=0}}$$

where Ug, x=0 is the velocity of the gas at the inlet and L is the typical dimension of the separator. Using these dimensionless parameters Equation (2) can be rewritten as

$$\tau\cdot\frac{U_{g,x=0}}{L}\cdot\frac{d^2\dot{x}}{d\dot{t}^2} + \frac{d\dot{x}}{d\dot{t}} = \dot{U}_g \qquad (5)$$

This equation evidence that the droplet trajectories, and therefore separation efficiency is only a function of the dimensionless Stokes number

$$St = \frac{4}{3}\cdot\frac{\rho_l}{\rho_g}\cdot\frac{d_p}{C_d}\cdot\frac{1}{\left|\bar{U}_g - \bar{U}_p\right|}\cdot\frac{U_{g,x=0}}{L} \qquad (6)$$

If Stokes law is used, friction factor is a simple function of Reynolds number

$$C_D = \frac{24}{\mathrm{Re}} \qquad (7)$$

and Stokes number, St, can be written in final form

$$St = \frac{\rho_l\cdot d_p^{\,2}\cdot U_{g,x=0}}{\mu_g}\cdot\frac{1}{18\cdot L} \qquad (8)$$

As showed in the previous analysis separation efficiency is a function of Stokes number, for this reason it is possible to assume that ηs=St. Therefore separation efficiency of a single bend is a function of drop size, dp, of gas velocity, Ug, x=0, and of a typical length, L.

To predict the efficiency of industrial separators, it is necessary to introduce the dependency from the number of bends, n. Generally a partial remixing of drops after each bend is assumed and the following expression is applied.

$$\eta_n = 1 - \left(1 - \eta_s\right)^{m\cdot n} \qquad (9)$$

The remaining factor, m has been studied by several authors /5/6/7/ and it changes in the range of 0.5-1. In this paper the approach of Ushiki /8/ has been u sed. This author assumed total remixing after each curve, and there m=1, and proposed to consider that the first bend contributes only at 50%. This assumpation leads to the final form

$$\eta_n = 1 - \left(1 - \eta_s\right)^{n-0.5} \qquad (10)$$

EXPERIMENTAL RESULTS

In this paragraph will be shown experimental results obtain for the separation of water drops from an air stream, working close to atmospheric condition.

For a correct design, besides separator efficiency, it is necessary to know the minimum dimension of the drops that are separated with 100% of efficiency. This parameter usually is called d_p 100 and derives directly from the expression of single bend efficiency. Using the approach proposed in the previous paragraph, this parameter can be evaluated as

$$d_p^{100} \doteq \sqrt{\frac{18 \cdot \mu_g}{\rho_l \cdot U_g} \cdot L} \qquad (11)$$

In the following figure the experimental data and relation (11) have been plotted versus gas velocity, the agreement appears to be fulfilled. This result shows, as the approach suggests in the previous paragraph that this method can be easily adopted to evaluate the dimension of the drops whose separation efficiency is 100%. To complete the analysis it is necessary to understand the influence of the number of bends. For this goal two different separators, with 3 and 4 bends, have been tested.

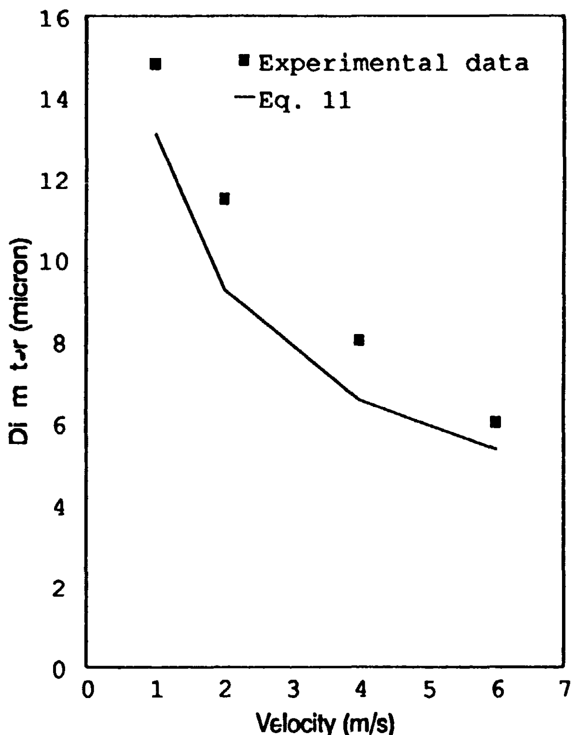

Figure 2 comparison between experimental and computed value of Dp100

In figure (3) the experimental results obtained with a separator with 3 bends have been plotted versus Stokes number, whereas in figure (4) have been plotted with the same results obtained with a separator with 4 bends.

Some interesting results have to be underscored. First of all from the comparison of figure 3 and figure 4 the equation of Ushiki, seems to provide a correct prediction of the influence of the number of bends. Another interesting observation derives from the analysis of the gas velocity. Both the figures show that for velocity of two m/s and more, the experimental efficiency curve seems to be independent from this parameter whereas if gas velocity is 1 m/s, for a constant value of the Stokes number, the experimental efficiency is lower. There results can be explained analyzing the equation adopted to compute the influence of bend number. Ushiki suggested eq(10) assuming complete drop mixing after each bend; this assumption is correct only if gas phase regime is turbulent.

If Reynolds number for stream gas is computed it is possible to check that the transition between laminar and turbulent flow occurs when gas velocity if equal about to 1.1 m/s and this explains the discrepancy observed in figures 3 and 4.

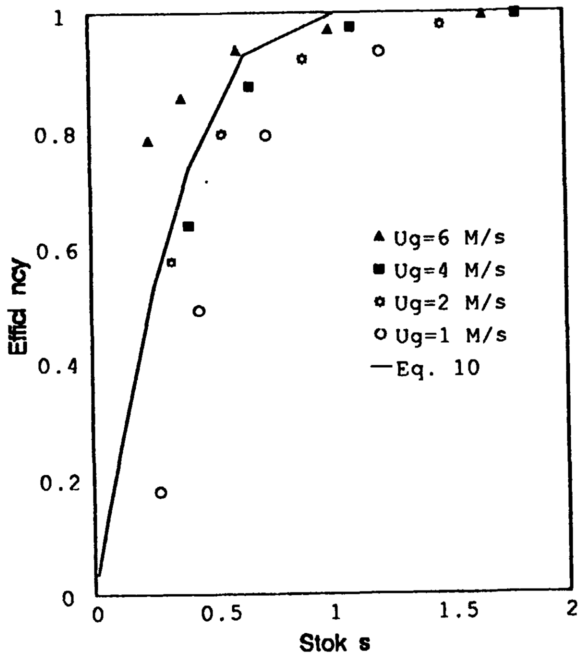

Figure 4 Comparison between experimental and computed value of efficiency abatement. Vane type demister with 3 bends

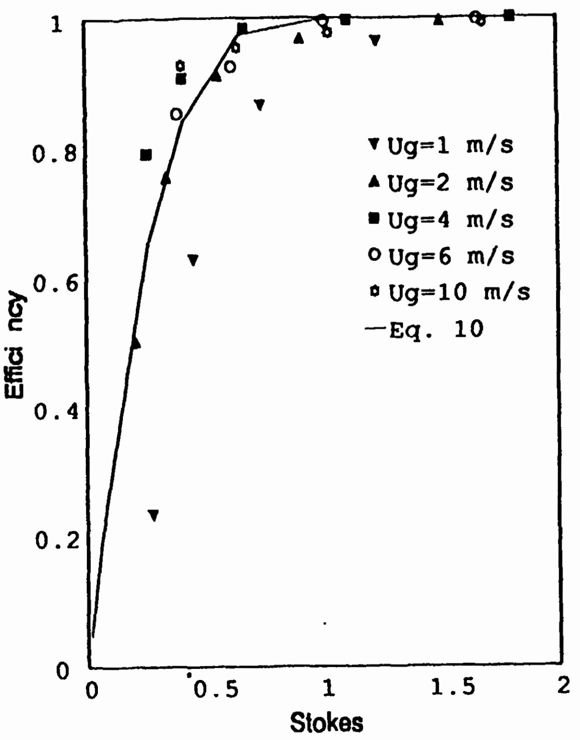

Figure 4 Comparison between experiment and computed value of efficiency abatement. Vane type demister with 4 bends

CONCLUSIONS

The goal of this work is to look for the efficiency of industrial vane type demisters that can be used in geothermal plants. A correct design will reduce scaling and corrosion in the turbine.

For this goal some industrial Vane type demisters have been experimentally tested. This analysis shown that:

- efficiency seems to be only a function of Stokes' number if Reynold's number is sufficiently high
- influence of the number of bends has been well predicted by Ushiki relation.

The experimental data indicate this type of separator allows high abatement efficiency also at low gas velocity.

Measurements of the Dp100 showed that this equipment allows us to obtain 100% of separation efficiency if the drops have dimension greater than 6 um.

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NOMENCLATURE

C_d	friction factor
d_p	drop size
d_p^{100}	Minimum drop size with separation efficiency of 100%
L	Typical dimesion of the separator
m	remixing factor
n	number of bends
U_g	gas velocity
U_p	drop velocity
Re_g	$\frac{\rho_g \cdot d_p \cdot U_g}{\mu_g}$ gas Reynolds number
St	Stokes number
η_n	total efficiency
η_s	efficiency of a single bend
μ_g	gas viscosity
ρ_g	gas density
ρ_l	liquid density
τ	characteristic time Eq()

SUPERSCRIPT

Dimensionless

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