EXPERIMENTAL STUDY OF GAS CLEANING BY A WET APPROACH VENTURI TYPE

IGO SERGE WENDSIDA [1*], BATHIEBO DIEUDONNE JOSEPH [2], ZEGHMATI BELKACEM [3], CHESNEAU XAVIER [3]

[1] *Institut de Recherche en Sciences Appliquées et Technologies (IRSAT/CNRST). Département Energie. 03 BP 7047 Ouagadougou 03, Burkina Faso.*

[2] *Laboratoire d'Energie Thermique et Renouvelable (LETRE). Université de Ouagadougou, 03 BP 7021 Ouagadougou 03, Burkina Faso.*

[3] *Laboratoire de Mathématiques et de Physique des Systèmes (LAMPS). 52 Avenue Paul Alduy 66860 Perpignan cedex 9, France.*

Abstract: The present work concern an experimental study of gas cleaning by a wet venturi scrubber. The water is introduced before the convergent and streams as a liquid along the venturi walls. Hydrodynamics, mass and thermal mechanisms occurring in the venturi tube and the scrubbing process are investigated in detail. Results show that the maximum density of water vapor resulting of vaporization of the liquid film is observed in the venturi throat. In addition, the collect efficiency increases as the inlet gas velocity and the scrubbing liquid flow rate increase.

Keywords: venturi; wetted approach type; liquid film vaporization; collect efficiency.

1. INTRODUCTION

Wet scrubbers are gas cleaning devices which utilize liquid in form of spray to collect particles from effluent gasses. That is why they are also called gas-liquid contactors. Among these scrubbers, venturi type are widely used because they have a high collect efficiency and are simple and easy to build with low cost maintenance [1]. However, the high collect efficiency is obtain at the expense of pressure drop and hence of the operations cost [2]. The collect mechanisms in wet scrubber are based on inertial impaction and interception while brownian diffusion assists in the removal of submicron particles [3]. These devices consist of channel with three parts: a convergent section, a throat and a divergent section or diffuser. Three types of venturi are usually used: the Pease-Anthony type where the liquid is introduced in the throat and sprayed by the high velocity of gas [4], the ejector type where the liquid is sprayed by atomizers before introduced [5] and the wetted approach type where liquid is introduced before the convergent as a film streaming along the venturi tube walls [6]. Here, droplets are formed due to the gas shear on the liquid film causing his vaporization. Of the three types of venturi, the wet approach type seems more interesting because it is adapted for hot gas flow, adhesives and corrosives dust [7]. Moreover, if there is a need to cool the venturi wall, the liquid film would enhance heat transfer [8, 9, 10]. Despite this, the wet approach type has not received much attention in previous studies. Major studies have focused on the Pease-Anthony type or the ejector type. However, Azzopardi and co-workers [11, 12, 13] have shown that whatever the mode of introduction of liquid, there will always be a fraction of the liquid streaming as a liquid film along the venturi walls. This fraction of film will influence the pressure drop and the collect efficiency of the venturi. Their works have been extended by S.Viswanathan [14] who developed a correlation

* Corresponding author, email: sergesigo@yahoo.fr

using experimental data to calculate the average fraction of liquid flowing along the wall. Later, D. Fernandez et al. studied experimentally gas/liquid flow in laboratory-scale venturis and conclude that the fraction of liquid remaining as film is correlated in terms of Weber number based on conditions at the throat entrance [15].

As seen, experimental studies in wet approach venturi type are scarce and limited. Therefore, the objective of this work is to study liquid film vaporization and hydrodynamics effects, and their influences on the particles collection efficiency.

2. MATERIAL AND METHODS

A centrifugal fan (CBT-60-Code 00626) with a power equal to 0.25 KW and whose speed of rotation (2800 tr/min) is equipped of a variable speed drives (Altivar-Télémécanique at V-18V118M2), draws pollute air and injects it into the venturi. Water is taken from domestic water supply system, metered by calibrated rotameter (Gilmont Instruments N 60651-60750) and introduced through an injection device upstream the converger for making a thin water film streaming along the walls. The interaction between the water film and the flow causes the vaporization of the water film at the crossing of the converger. Droplets resulting of the vaporization of liquid film interact with the particles causing their collect. The experimental arrangement for which the present study is carried out is shown in Figure 1.

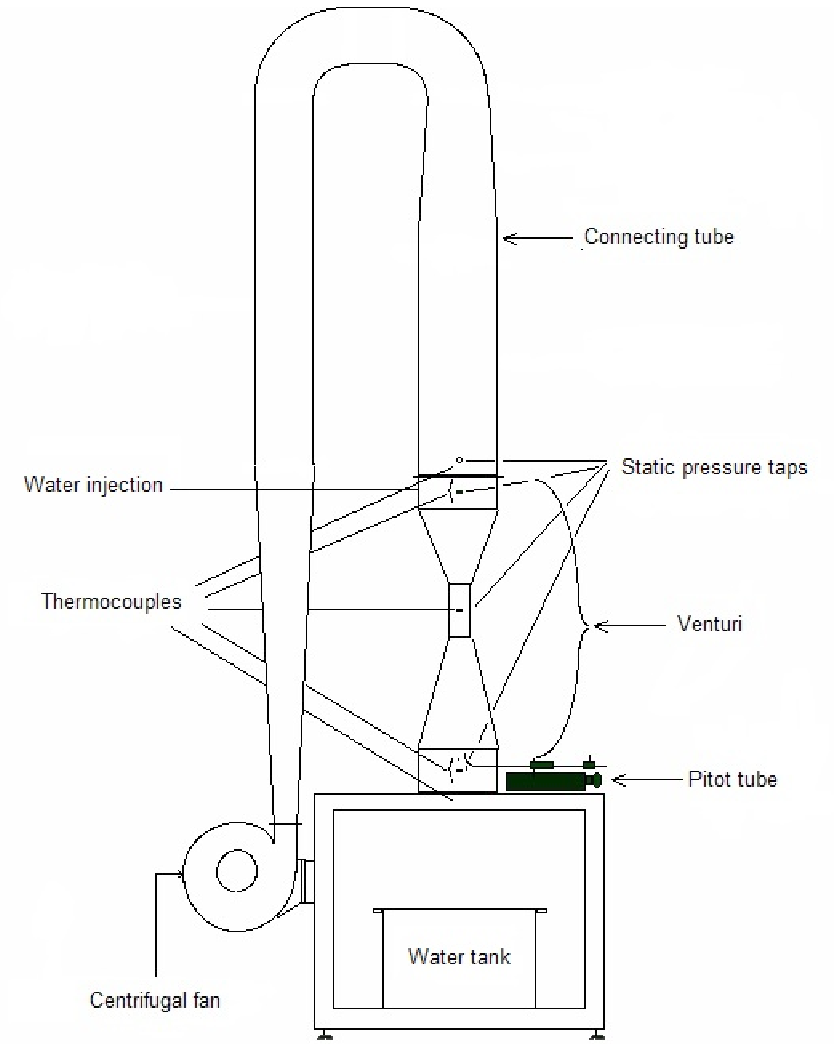
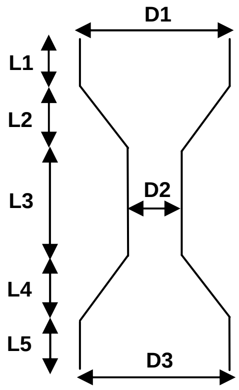


Fig. 1. Schematic of experimental set-up.

The venturi is built with transparent plastic (plexiglass) of thickness equal to 5 mm except the walls which are in aluminum. The venturi geometry is presented in Figure 2.



D1	200 mm
D2	50 mm
D3	200 mm
L1	100 mm
L2	200 mm
L3	150 mm
L4	300 mm
L5	150 mm

Fig. 2. Geometry of venturi, mm.

2.1 Experimental protocol for measurements

Velocity measurements are performed by a Pitot tube. The Pitot tube is connected to a type MMVM manometer-velocimeter for velocity and pressure data acquisition. The device tolerance is ± 0.1m for velocity and ± 2Pa for pressure. Pressure gradients between the inlet and the throat (ΔP1) and between the throat and the outlet (ΔP2) are measured by the manometer-velocimeter. The wall temperature is measured by T type thermocouple while ambient temperature is measured by K type thermocouple. The outputs of the thermocouples and the manometer-velocimeter are connected to a digital multimeter (Keithley-2700) which contains a GPIB card allowing a real-time acquisition of data by a computer.

T type thermocouple whose range of use is 0 to 400°C tolerance is ± 0.4°C and K type thermocouple whose range of use is 0 to 1100 °C tolerance is ± 1°C.

2.2 Experimental protocol for collect efficiency (CE) calculation

The particles used in the experiment are iron filings. A size study has permitted to isolated particles with diameter approximately equal to 10^{-4}m. Initially, a quantity of particles is weighed. M is its weight. The collection efficiency is deduced from the difference between the weight of water for a polluted air flow (M1) and of an unpolluted air flow (M0) for a same period of scrubbing. For this, at a fixed inlet air velocity and a water film flow imposed, the water is collected at the exit of the venturi and weighed. The collection efficiency is calculated by dividing the mass of particles collected (MPC) by the mass of particles introduced:

$$CE = \frac{MPC}{M} \tag{1}$$

where:

$$MPC = M1 - M0 \tag{2}$$

Balance KERN 442-51 used for measures tolerance is done by the constructor:

$$\Delta\left(Measure\right) = 0.0014 + 1.8 \times 10^{-5} \times m_w \tag{3}$$

where m_w is the measure read. So the tolerance for MPC and CE are respectively:

$$\Delta(MPC) = \Delta(M1) + \Delta(M0) \tag{4}$$

$$\Delta(\mathrm{CE}) = \mathrm{CE} \times \left[\frac{\Delta(\mathrm{MPC})}{\mathrm{MPC}} + \frac{\Delta(\mathrm{M})}{\mathrm{M}} \right] \quad (5)$$

3. RESULTS AND DISCUSSION

The velocity reaches the highest value on passing through the throat because of the effect of section area of this section (Figure 3). We note that the velocity has the same value upstream and downstream the convergent divergent because these two sections have the same dimension. The evolution of the pressure gradient is similar to that of the velocities and is conform to the venturi effects (Figure 4). The pressure gradient reaches a maximum value at the crossing of the venturi throat.

The temperature of the venturi internal wall increases as the water film flow rate increases (Figures 5 - 8). It is noted that for the values of water film flow rate equal to 60 and 70 lh^{-1}, the profile of the wall temperature has an inflection point for the values of air flow rate greater than 0.05 m^3s^{-1}. As the air flow in the venturi, the amount of potential energy is converted at the crossing of the converger into kinetic one causing the vaporization of an amount of the water injected upstream the converger. As a result, the air temperature reaches its wet bulb temperature which is inferior to the ambient tone equal to 20°C. Consequently, there is a heat transfer by convection and conduction through the wall of the venturi from the outside to the inside of the venturi causing an increase in the wall temperature. After the throat, the amount of energy carried away by the air-water droplets mixture is changed by the transformation of kinetic energy into potential energy causing an increase of the wall temperature compared to that observed upstream the throat.

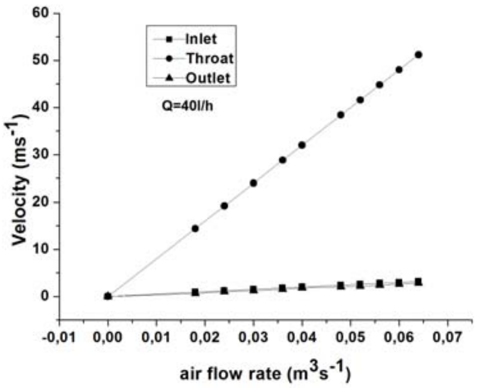


Fig. 3. Inlet, throat and outlet velocity versus air flow rate at the venturi inlet.

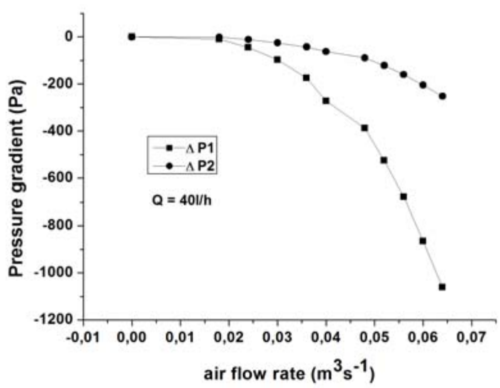


Fig. 4. Pressure gradient versus air flow rate at the venturi inlet.

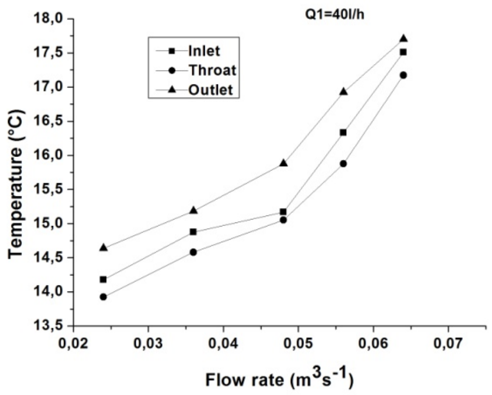


Fig. 5. Temperatures versus water film flow rate at the venturi inlet.

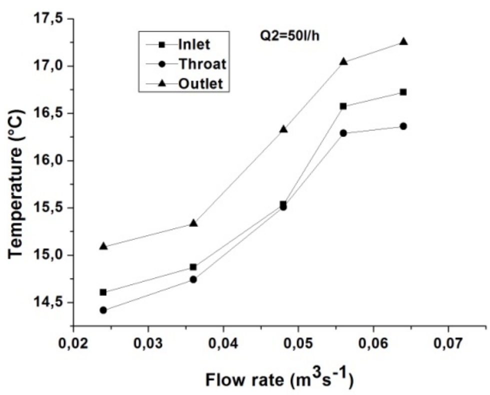


Fig. 6. Temperatures versus water film flow rate at the venturi inlet.

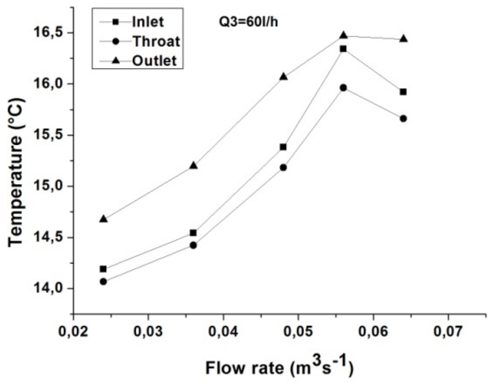


Fig. 7. Temperatures versus water film flow rate at the venturi inlet.

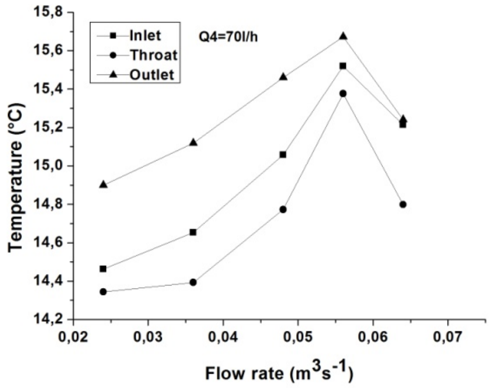


Fig. 8. Temperatures versus water film flow rate at the venturi inlet.

The temperature of the throat wall is less than that measured upstream and downstream of the throat because the flow velocity of the air-droplets is maximum at this section causing a maximum vaporization of the liquid film. This result is an agreement with Azzopardi et al. who note that for wetted approach venturi type, a significant atomization of the liquid film occurs in the throat region, but not all of the liquid is atomized in the throat [16]. In addition, the temperature of the air-water droplets is equal to the wet bulb temperature and the transfer between air and the internal wall are all higher as the air-water droplets velocity is great. It is noted that the difference between the temperature upstream and downstream the throat is higher as the air flow rate is low because the heat transfer between the internal venturi wall and air is an increasing function of the flow velocity. The inflection points observed for the air flow at 60 and 70 lh^{-1} seems indicated the values of air and water film flow rate upstream the converging for which the vaporization of water is complete.

Table 1 and Table 2 show the detail of collect efficiency calculation respectively at a fixed liquid flow rate and at a fixed air velocity.

Table 1. Experimental data for the collect efficiency calculation at a fixed liquid flow rate.

Liquid flow rate: 40l/h; Depollution duration: 60s					
inlet air velocity (m/s)	M (g)	M0 (g)	M1 (g)	MPC (g)	CE
3.2	0.500 ± 0.001	538.00 ± 0.01	538.30 ± 0.01	0.30 ± 0.02	0.60 ± 0.04
2.8	0.500 ± 0.001	538.00 ± 0.01	538.29 ± 0.01	0.29 ± 0.02	0.58 ± 0.04
2.4	0.500 ± 0.001	538.00 ± 0.01	538.26 ± 0.01	0.26 ± 0.02	0.52 ± 0.04
1.8	0.500 ± 0.001	538.00 ± 0.01	538.17 ± 0.01	0.17 ± 0.02	0.34 ± 0.04

Table 2. Experimental data for the collect efficiency calculation at a fixed air velocity.

Air velocity: 3,2ms^{-1}; Depollution duration: 60 s					
Liquid flow rate (l/h)	M (g)	M0 (g)	M1 (g)	MPC (g)	EC
40	0.500 ± 0.001	538.00 ± 0.01	538.30 ± 0.01	0.30 ± 0.02	0.60 ± 0.04
50	0.500 ± 0.001	763.00 ± 0.02	763.34 ± 0.02	0.34 ± 0.04	0.68 ± 0.08
60	0.500 ± 0.001	963.00 ± 0.02	963.36 ± 0.02	0.36 ± 0.04	0.72 ± 0.08
70	0.500 ± 0.001	1103.00 ± 0.02	1103.37 ± 0.02	0.37 ± 0.04	0.74 ± 0.08

Figures 9 and 10 present respectively the collection efficiency versus air velocity and versus water film flow rate. As seen in Figure 3, the augmentation of inlet air velocity lead to an increase of throat velocity. This augmentation causes an increase of the vaporization and hence the concentration of water droplets. As a result, particles-droplets interactions increase and the collection efficiency is better. The increase of the inlet water flow rate has the same effect as the air flow rate one (augmentation of the water vaporization). Therefore, the collection efficiency also increases as the water film flow rate increases. This result is an agreement with the work of Shear Viswanathan who has demonstrated that in Venturi scrubbers, and for large particles, the collect efficiency increases with the increase of the throat velocity and the liquid to gas ratio [17].

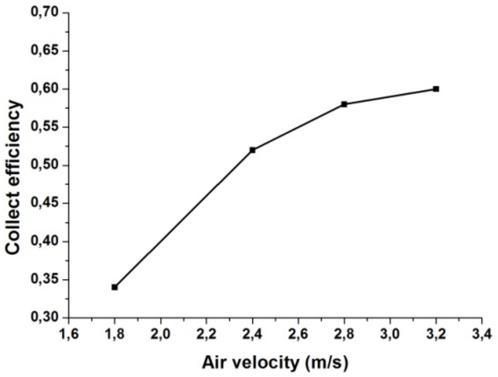


Fig. 9. Collect efficiency versus inlet air velocity in the venture.

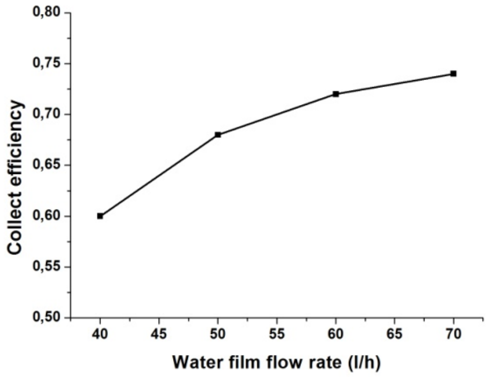


Fig. 10. Collect efficiency versus inlet water film flow rate in the venture.

4. CONCLUSIONS

Using an experimental venturi, we have highlighted the hydrodynamic, mass and thermal phenomena occurring in a wet approach venturi scrubber type and calculated its collection efficiency in various parameters of operation. The main results are summarized as follows:

- the increase of the inlet air flow and water film flow rates lead to an intensification of the vaporization of the water film streaming along the Venturi wall;
- the maximum vaporization of the liquid film occurs in the Venturi throat;
- the intensification of the film vaporization increases the particles-droplets interactions and lead to a better collect efficiency.

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