High performance air-assisted flare design for low waste gases flow conditions

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Abstract

Air-assisted flares have been used to achieve smokeless combustion of waste flare gases from refineries and chemical plants. Recent work has focused on evaluating an air-assisted flare with a new tip designed to operate with high mixing energy across the full range of firing rates. This flare tip can efficiently handle low flow conditions (purge flow) of waste gases that result in low combustion efficiency and associated flare performance. During the fired test, various operating conditions were used to evaluate flare performance of the new tip. Ten cases with different waste gas flow rates with varying air flow rates were employed. Initially, the flare was tested without assist medium followed by testing with assisted media. Combustion product gases were analyzed to quantify flare performance. Results from different tests with and without assist air were compared to each other to evaluate the flame behavior from the new flare tip. Results confirmed that flaring waste gases was has significantly enhanced using the new flare tip design.

Introduction

The waste gases from various equipment in any chemical and petrochemical plant must be efficiently controlled and discharge through flaring process. The mechanical equipment that used to ensure safe and efficient discharge are the flares (Smith, et al. 2018). Flares are classified according to the assistant medium into steam-, air-, pressure-, and non-assisted flare (Castineira and Edgar 2006). The objective of using assistant medium is to promote the mixing between waste gases and the surrounding air, induced air to the combustion zone, and to enhance combustion process. Different parameters are affecting the flaring process which can be the flowrate and heating value of waste gases, the assistant medium amount, and the wind. Purge flow conditions in flaring operation is a common practice in chemical and petrochemical plants. The waste gases under such flow conditions do not have the required momentum to provide the efficient mixing energy between the waste gases and the surrounding air. Therefore, the flare performance under the purge flow conditions declines which leads to release of unburn hydrocarbons and soot (Allen and Torres 2011).

To overcome the problem of purge flow condition in flaring process, this paper presents the developed air-assisted flare tip design. This design is capable to efficiently operate under wide range of waste gases flow conditions ranging from purge to high flow conditions.

Flare design

Two designs were used to develop the final design of the new tip. The first design was used to perform the cold flow tests which have no combustion. In cold flow design, the air was injected radially with no angle (perpendicular direction into the waste gases flow) (Alhameedi, et al. 2020). The other design uses a radial jet of air injected inwardly with angle into waste gases flow to adjust the waste gases flow cross sectional area. The hot flow design includes two plate rings made of stainless steel with dimensions of 6-inches for the inner diameter, 12-inch for the outer diameter, and 1-inch for the thickness of the outer diameter. The inner side of both plates have a specific configuration to provide the required radial slot to form the radial jet. The radial jet air was provided through a n industrial compressor that can give high flowrate of air. The air from compressor was supplied into the radial jet configuration through eight taps in the bottom of the lower plate. These eight taps ensure the equality of flow through the plates and hence the uniformity of jet flow. For the cold flow test, the horizontal radial slot jet without inclination was used as shown in the Figure 1.

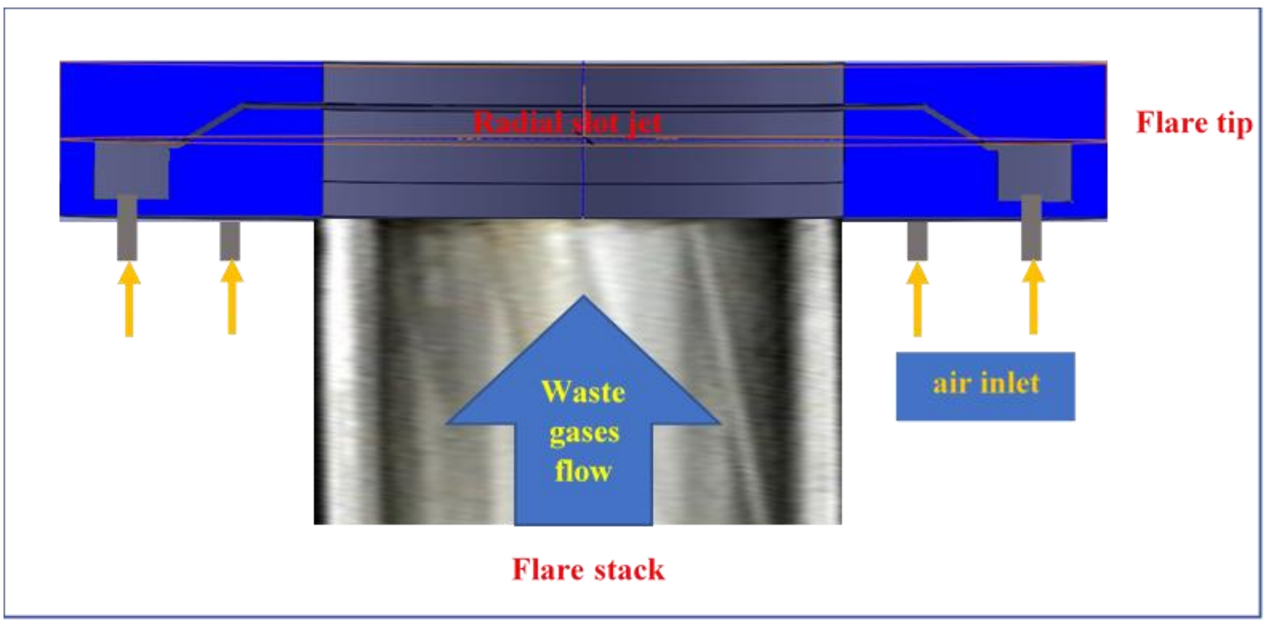

Figure 1 – Aero-nozzle flare tip design

Testing

To assess the new design performance, cold (no combustion) and hot flow experiments have performed for different flow conditions.

Cold flow testing

Series of experiments of cold flow (no combustion) have performed to assess the new design effectiveness on the flow field of waste gases. The purpose of this test in addition to evaluate the effect of using radial slot jet on the flow field was to collect sufficient experimental data. These data can be used to validate the developed CFD model that required to find optimum design parameters. Air was used as fluid medium for both the cross flow and for the jet. Hot wire anemometry was used to measure the local velocity value in different radial and axial locations above the flare tip. Three different jet velocities of 4.1, 7.3, and 10.4 m/s were used. The waste gases flow rate was a 0.6 m/s for all tests (Alhameedi, et al. 2020).

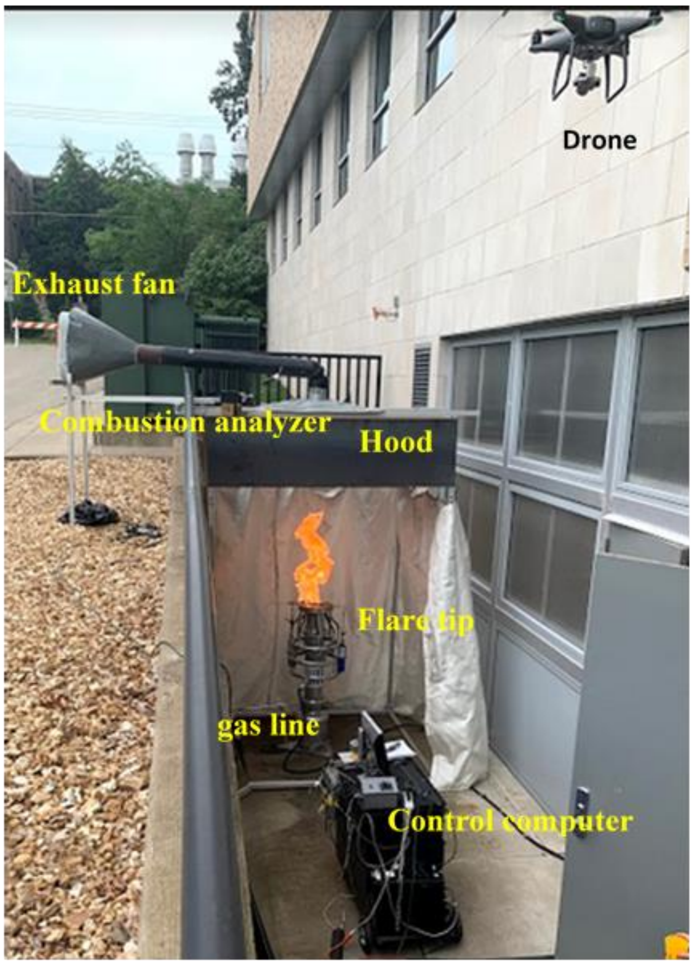

Figure 2 - Flare Test Setup

Hot flow testing

The hot flow testing was carried out in open environment. Figure 2 shows the flare setup components. The combustion product gases were collected through the hood and using exhaust fan. Combustion analyzer was used to measure the concentration of carbon monoxide, carbon dioxide, and unburned hydrocarbon. These gas concentrations are required to estimate the combustion and destruction removal efficiency that are required to quantify the flare performance. Different flow conditions of waste gases and jet flow were used.

Results and Discussion

Cold flow

The experimental results of the cold flow testing are shown in Figure 3. As can be seen in this figure, the centerline velocities of waste gases were increased above the set velocity value after injection point. This means that the radial slot jet has enhanced the flow velocity of the waste gases. Therefore, with the new tip design the operator can adjust the exit area of the waste gases flow.

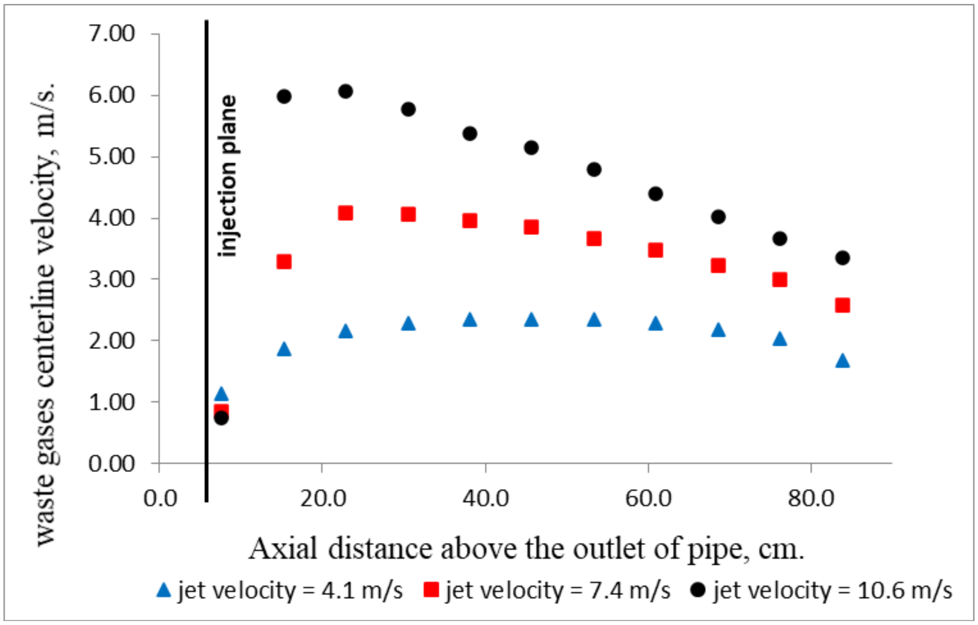

Figure 3 - Experimental measurements of flare gas centerline velocity for different slot jet flow

Hot flow test

Figure 4 shows the effect of using inclined radial slot jet on the flaring process. As can be seen in Figure 4a, the flame is short and close to the tip which would damage the flare tip due to high temperature operation which would reduce the tip operating life. **Error! Reference source not found.**b shows the effect of injecting 8 cubic feet per minute assist air through the radial slot. As is shown, the flame is very stable with no combustion occurring on the flare tip surface. Moreover, combustion near the flare tip is clean with cooler blue flame highlighted in red circle. As injected assist air through the slot is increased, with a constant flow of waste gas, the combustion is enhanced due to increased turbulent mixing which leads to better flare performance. Flame shape and intensity at higher assist air flows are shown in Figure 5 and Figure 6. As shown, as assist air flowrate increases the flame is stretched out and becomes more translucent. This indicates higher destruction efficiency of the flare gas and less soot formation. Optimum flare operation can be established by comparing air flow to measured CO and soot concentrations above the flare.

The test facility shown in Figure 2 includes a hot above the flare flame which captures the flare plume. The exhaust duct includes a sample port where gas analysis is conducted to quantify flare performance. Results from this test will be presented in a future published paper but the flame shape and intensity are good indications of flare performance.

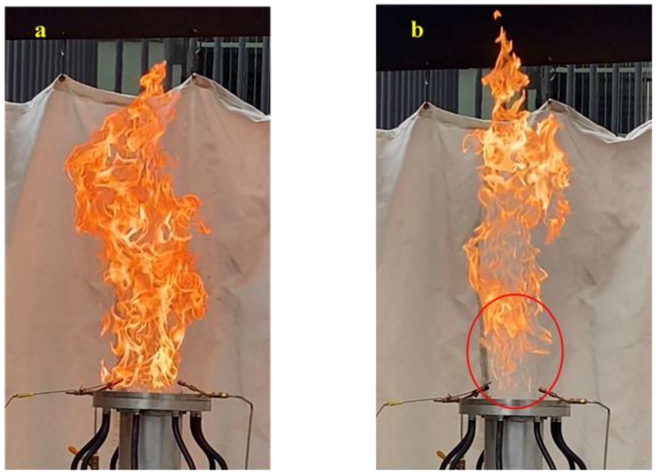

Figure 4 - Flame above Flare Tip with 20 L/min propane with: a) 0 cfm assist air, b) 8 cfm assist air

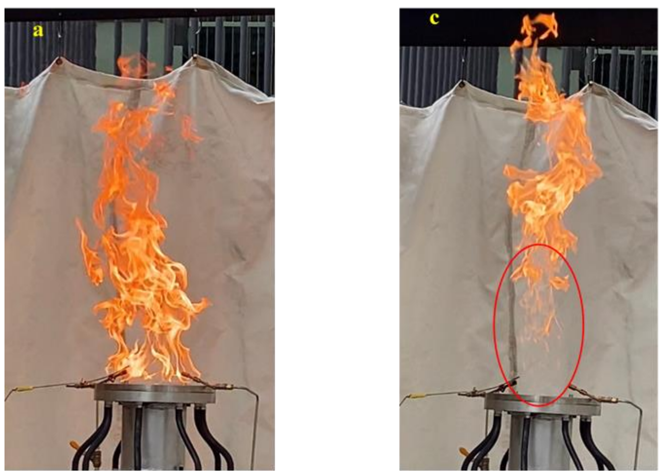

Figure 5 - Flame above Flare Tip with 20 L/min propane with: a) 0 cfm assist air, b) 10 cfm assist air

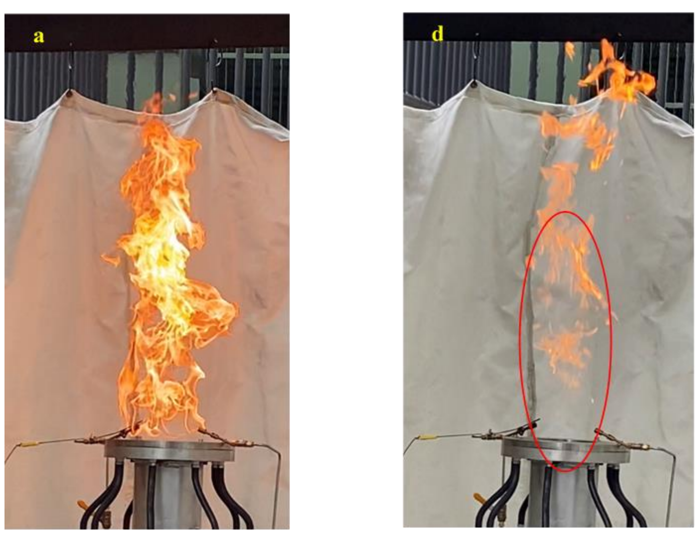

Figure 6 - Flame above Flare Tip with 20 L/min propane with: a) 0 cfm assist air, b) 12 cfm assist air

Conclusions and Recommendations

A new air-assisted flare tip has been designed, analyzed with CFD, then built and tested under several firing conditions. The new design was shown to be capable of efficiently operating at very low flare gas flow rates. Cold flow tests have been conducted to assess the mixing characteristics of new tip design. Measurements confirm the new tip design significantly increases mixing between the flare gas and assist air by reducing the effective tip exit flow area. Hot flow testing has shown that combustion is enhanced significantly by adjusting the injected assist air through the inclined radial slot in the tip. The new flare tip design promotes turbulent mixing of waste gases and assist air. The resulting flame can be carefully controlled by adjusting the assist air flow rate.

References

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