Emission Reduction Study When Gas Flaring is Inevitable

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The scope of this Study is to examine and evaluate the effectiveness of different design measures aimed to reduce the emissions of Oil and Gas plant flares, mainly in terms of heat radiation, flammable and toxic gases.

For the consequences simulation, the internationally recognised software Flaresim (developed by Softbits) and Phast (developed by DNV) have been used.

The main reference, which was used as Base Case, was an onshore plant flare without any particular design measures, that would reduce emissions, in place. A realistic case has been analysed: a flared stream composed mostly by methane, with a significant content of Hydrogen Sulphide (H_2S). Furthermore, the heat radiation, the flammable gas dispersion and the toxic gas dispersion in case of flame-out were evaluated.

Following the Base Case, Sensitivity Cases for reduction of radiation emissions were necessary to be performed, such as oxygen addition, steam addition, tip selection, stack height elevation, multiple flares installation, as well as combinations of those cases.

The purpose was to define the effectiveness of each of the proposed design solution and conclude in the one that would give the best possible results in terms of emission reduction.

1. Introduction

In many parts of the world and especially in the Middle East, the fast track development of Processing Facilities to produce oil meant that, as a temporary measure, the majority of the gas produced from the well separation would need to be burned. The result constitutes to massive flares burning hundreds of thousand kg of gas per hour.

The majority of the flares burning these large quantities of gas are only designed to operate during emergency. This puts a number of restrictions on operators as the flare emissions including heat radiation, flammable and toxic gases are beyond the acceptable limits. At the same time, the lack of gas treatment facilities means that the flaring is continuous and happening in many oil fields.

Figure 1: Continuous Flaring of Large Amounts of Gas

It is therefore essential to look into solutions that are practical and feasible, in order to reduce emissions in Processing Facilities that have no gas treatment available and are obliged to burn the gas.

Figure 2: Continuous Flaring of Large Amounts of Gas

The current study will investigate a realistic scenario of gas flaring. At first, the input data, design criteria and modelling tools will be presented in order to have a good representation of the assumed scenarios used to obtain the results. Afterwards, the Base Case will be presented, followed by the results obtained by the addition of a number of safety measures in order to reduce emissions, assuming the same amount of gas burning.

The flare system considered as the Base Case in this Study is constituted by two flare systems: HP/LP (High Pressure/Low Pressure) Flare and LLP (Low Low Pressure) Flare. These two flares are arranged on the same flare stack (similar to Figure 2).

The effects of safety design measures, as oxygen addition, steam addition, tip selection, stack height elevation will then be evaluated step by step. The installation of an additional flare stack with similar characteristics will also be studied.

2. Description

The assumed flare is part of a Central Processing Facility, initially designed for emergency flaring. Due to unavailability of the Gas Treatment Plant, all gas from the Processing Facility -that is not used for power purpose-, goes to the flare.

The flare sits downwind of the central processing facility, close to the facility fence.

As seen in Figure 3, the sterile area is the one that was initially calculated for emergency flaring and does not surpass the plant boundary.

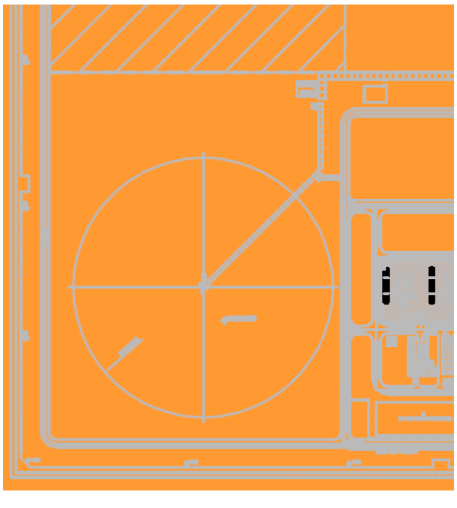

Figure 3: Flare Sterile area boundary and plant fence (bottom and left)

3. Input Data

3.1 Climatic conditions

The climatic conditions used for the heat radiation, flammable and toxic gas dispersion studies are summarised in the following.

- **Ambient Temperature (annual average value):** 25 °C;
- **Ambient Humidity:** 18%;
- **Solar Radiation:** 1 kW/m^2;
- **Wind Direction:** NW;
- **Wind Reference Height:** 10 m;
- **Wind Speed (for radiation calculation):** 25 m/s;
- **Pasquill Stability Class (for dispersion calculation):** 5D / 0.5 F (1F)

3.2 Capacity

The flare stack, constituted by two flare systems, HP/LP and LLP flares, has been modelled for the following capacity, considering the case of continuous flaring:

- **HP/LP flowrate:** 319916 kg/h
- **LLP flowrate:** 95375 kg/h.

3.3 Mechanical and Structural Characteristics

The mechanical and structural characteristics of the base case flare considered in this study are reported in the following:

- **Stack Height:** 55 m;
- **Tip Length:** 3 m;
- **Tip Type:** Generic Pipe;
- **Assist Fluid:** Air;
- **HP/LP Flare:** **Inlet Tip Diameter:** 36″;
  Exit Tip Diameter: 32.5″;
  Blowers: 2 on duty + 1 spare;
  Total Air Flow: 356117 kg/h;
  Maximum Allowable Backpressure at Stack Base: 0.3 barg;
- **LLP Flare:** **Inlet Tip Diameter:** 24″;
  Exit Tip Diameter: 20″;
  Blowers: 1 on duty + 1 spare;
  Total Air Flow: 178059 kg/h;
  Maximum Allowable Backpressure at Stack Base: 0.15 barg.

3.4 Composition

The flared stream is mainly composed by methane, ethane and propane and has a significant content of H_2S (about 1.33 %).

4. Design Criteria

4.1 Heat Radiation Values

The following heat radiation threshold values have been considered, based on API 521, in case of continuous flaring:

- The radiation of 9.46 kW/m² (including solar radiation) shall not be reached on the ground level at the base of the flare stack;
- The radiation of 1.58 kW/m² (including solar radiation) shall not be reached outside the sterile area and outside the plant boundary (fence).

Based on the above, inside the sterile area process or utility equipment, buildings, plant boundary, main plant road and manned area should not be present.

4.2 Flame out

In case of accidental flame out, the flammable envelopes corresponding to ½ LFL concentrations shall not reach areas where personnel or ignition sources could be present (outside the Sterile Area).

In case of accidental flame out, the toxic envelopes corresponding to IDLH and LCLo doses shall not reach areas where personnel could be present (outside the Sterile Area).

The reference toxic substance for the flared gas is H_2S, for which the following values have been considered:

- IDLH (H_2S): 100 ppm;
- LCLo (H_2S): 600 ppm/30 min (derived value 60 ppm).

In case the above requirements are not respected, adequate mitigation and safety measures would need to be put in place in order to avoid possible hazardous scenarios for operators and external people and to preserve the safety of the installation.

5. Modelling Tools

The Flaresim software (Ref. [1]) has been used for the thermal radiation and flammable gas dispersion modelling, whereas the Phast software (Ref. [2]) has been used for the toxic gas dispersion modelling, in case of flame out.

In particular, the following models have been applied:

- Chamberlain model for the thermal radiation simulation;
- Neutral Gas Dispersion for the flammable gas dispersion simulation;
- Dense Gas Dispersion for the toxic gas dispersion simulation.

6. Base Case Results

The following results have been obtained for the Base Case (distance of Flare Stack from Plant Boundary is □230m):

<u>HP/LP Flare</u>

Tip Exit Velocity: 172.5 m/s;

Mach Number: 0.4736;

Backpressure at Stack Base: 0.142.

<u>LLP Flare:</u>

Tip Exit Velocity: 100.0 m/s;

Mach Number: 0.3243;

Backpressure at Stack Base: 0.093.

The heat radiation levels reached at the critical receptor points are the following:

- Flare Stack Base: 8.772 kW/m^2
- Plant Boundary: 2.323 kW/m^2

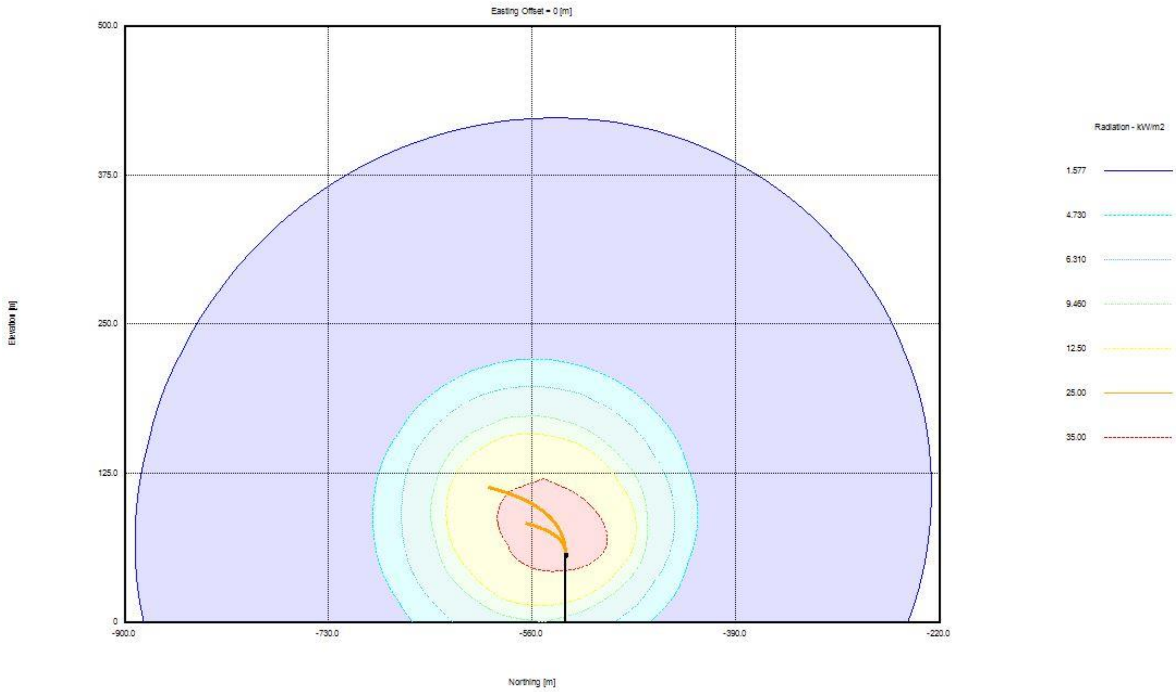

Figure 4: Heat Radiation Contours – Vertical View (Base Case)

The results show an acceptable value at the Flare Stack Base for thermal radiation. Later in the study, by investigating the Sensitivity Cases we will examine the changes made in terms of heat radiation at the Flare Stack Base in comparison with the Base Case.

The results also show a much higher than accepted level of heat radiation at the Plant boundary (acceptable limit 1.58kW/m^2). Reducing the heat radiation at the Plant boundary will be closely investigated in the Sensitivity Cases within this study.

The flammable gas dispersion, in case of Flame Out, has been evaluated for Pasquill Classes 5D and 0.5F. No credible dangerous scenarios, due to flammable gas dispersion, have been found in case of flare Flame Out on the ground level; the ½ LFL concentration does not reach the ground level. Therefore, flammable gas dispersion has not been considered for further sensitivity analysis.

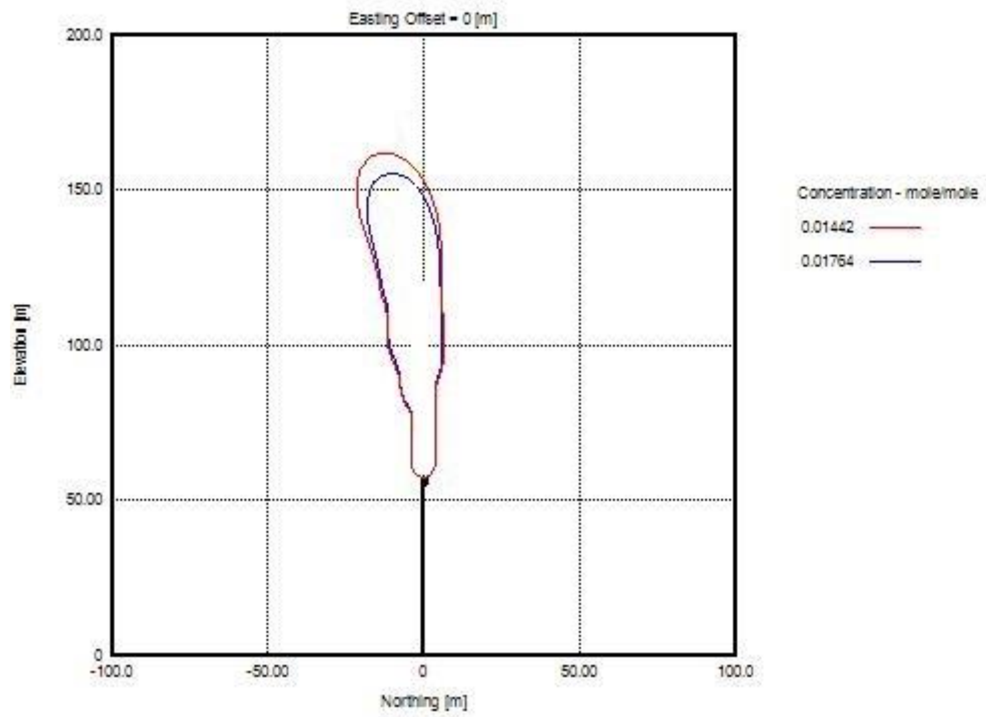

Figure 5: ½ LFL concentrations – Pasquill Class 0.5F (Base Case)

The toxic gas dispersion, in case of Flame Out, has been evaluated for Pasquill Classes 5D and 1F. No credible dangerous scenarios due to toxic gas dispersion have been found in case of flare Flame Out on the ground level; the IDLH and LCLo concentrations do not reach the ground level. Therefore, toxic gas dispersion has not been considered for further sensitivity analysis.

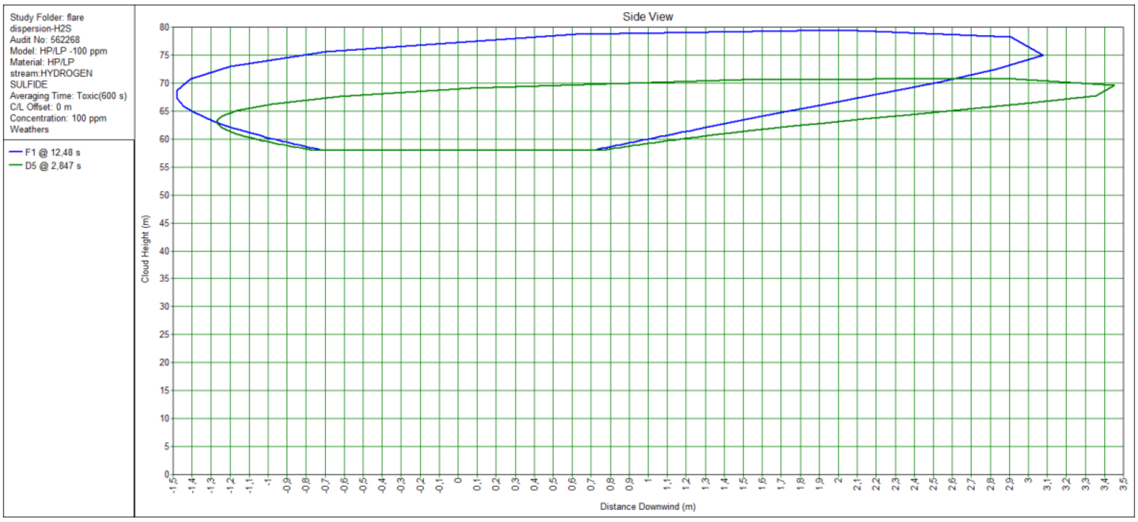

Figure 6: IDLH concentration – Pasquill Classes 5D / 1F (Base Case)

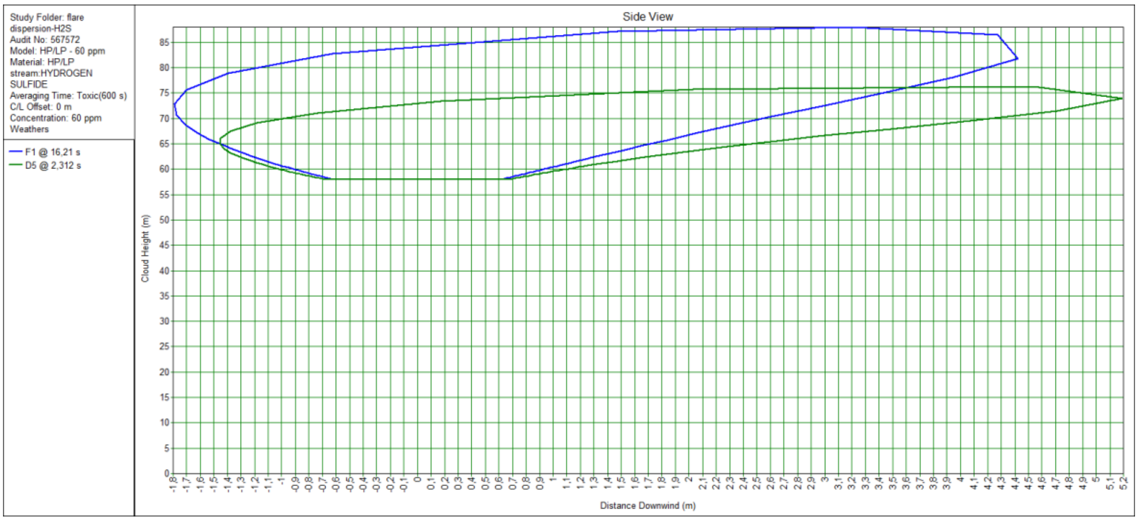

Figure 7: LCLo concentration – Pasquill Classes 5D / 1F (Base Case)

7. Sensitivity Analysis

In order to reduce the heat radiation level reached on the ground, at the critical receptor points (in particular at the plant boundary), the study evaluated the effects of the following safety design measures:

- Sensitivity Case 1: Increase of Flare Height.
- Sensitivity Case 2: Adjustment of Assisting Air Stream Flowrate in order to reach the 20% smokeless operation condition.
- Sensitivity Case 3: Increase of Assisting Air Stream in order to reach the 100% smokeless operation condition.
- Sensitivity Case 4: Implementation of Assisting Steam Stream for 20% smokeless operation condition.
- Sensitivity Case 5: Implementation of Sonic Flare Tip.
- Sensitivity Case 6: Installation of an Additional Flare.
- Sensitivity Case 7: Installation of an Additional Flare and Increase of the Height of Both Existing and New Flare Stacks.
- Sensitivity Case 8: Installation of an Additional Flare and Installation of Sonic Tip for Both Existing and New Flare.

The effects for each one can be seen in the following sections of this Study.

For sake of completeness, the case of “Absence of Assisting Air Stream (Comparison Case in Section 7.9 of this Study)” has also been evaluated, in order to demonstrate the difference in results in comparison with the -Sensitivity Cases conducted as part of this study.

7.1 Increase of Flare Height (Sensitivity Case 1)

The study has considered the possibility to increase the flare stack height in order to evaluate the effects in terms of heat radiation levels reached on the ground, at the critical receptor points.

In particular, a flare stack height of 70 m (67 m of stack plus 3 m of flare tip) has been taken into account.

The heat radiation levels reached at the critical receptor points are the following:

- Flare Stack Base: 7.004 kW/m^2
- Plant Boundary: 2.271 kW/m^2

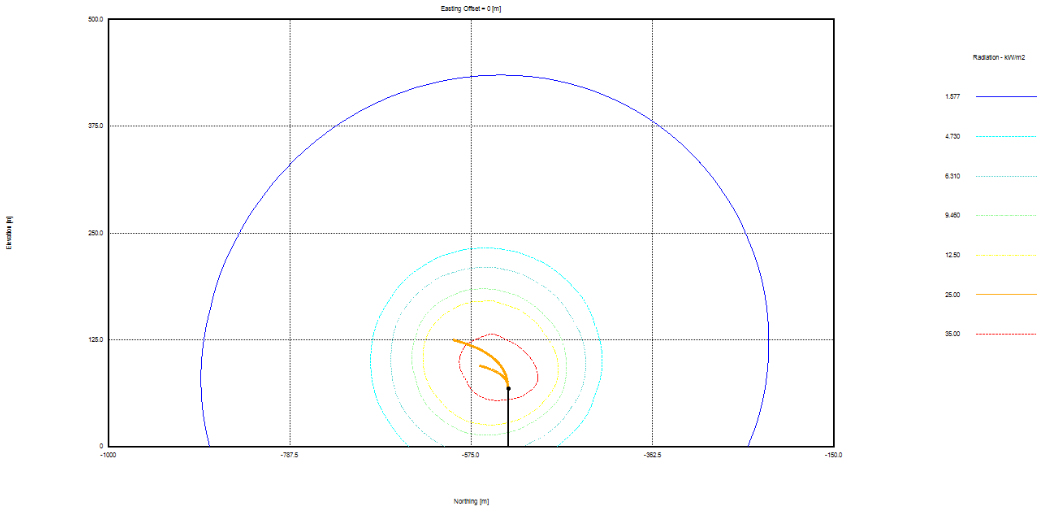

Figure 8: Heat Radiation Contours – Vertical View (Sensitivity Case 1)

The first value of 7.004KW/m^2 at the Flare Stack Base is -as expected- acceptable, only a bit lower than the Base Case.

The value at the Plant Boundary of 2.271 kW/m^2, although lower than the Base Case, is still not acceptable as it is higher than 1.58 kW/m^2.

In the subject case, there was a restriction on the allowable height but, as a general rule, more height would surely reduce the radiation at the plant boundary.

7.2 Adjustment of Assisting Air Stream Flowrate (20% smokeless operation) (Sensitivity Case 2)

As a next step, the possibility to adjust the assist fluid flow ratio (air stream) at the flare tip, in order to reach exactly the 20% smokeless operation, has been examined.

The following total air flow rates have been considered:
HP/LP Flare:
Total Air Flow: 319916 kg/h;

LLP Flare:
Total Air Flow: 95375 kg/h.

The heat radiation levels reached at the critical receptor points are the following:

- Flare Stack Base: 8.945 kW/m^2
- Plant Boundary: 2.366 kW/m^2

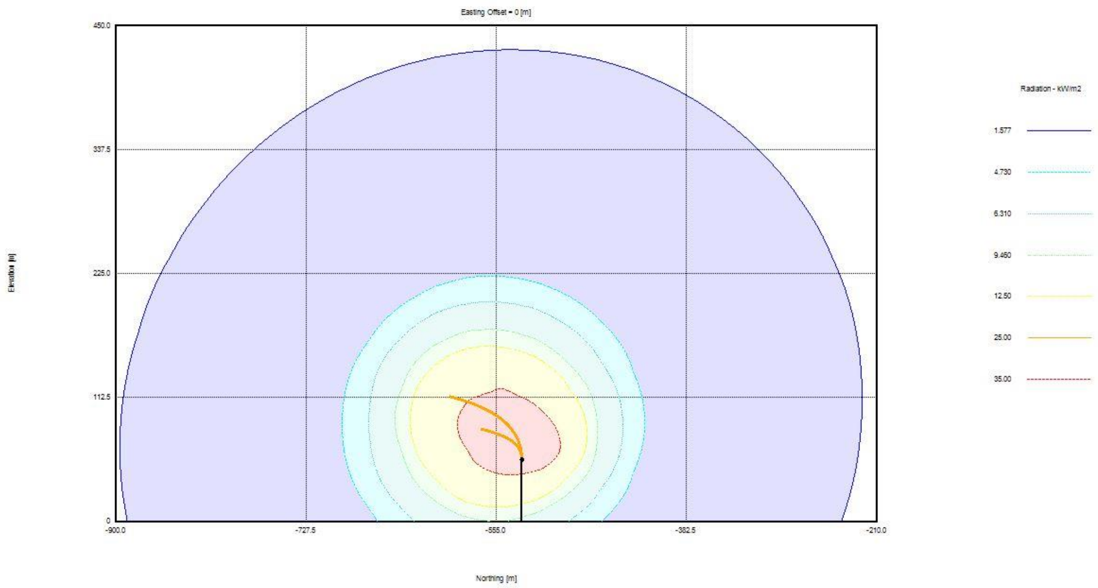

Figure 9: Heat Radiation Contours – Vertical View (Sensitivity Case 2)

The result shows that the adjustment of the air stream flowrate at the flare tip in order to reach exactly the 20% smokeless operation condition would give worse results than the results on the Base Case both at the Flare Stack Base and at the Plant Boundary.

This means that the Base Case represents already smokeless condition better than the 20%. Therefore, this adjustment does not represent a significant increase in terms of emission reduction.

7.3 Increase of Assisting Air Stream (100% smokeless) (Sensitivity Case 3)

Taking into account the results of the Sensitivity Case 2, the possibility to increase the assist fluid flow ratio (air stream) at the flare tip, in order to reach the 100% smokeless operation, has been examined.

The following total air flow rates have been considered:

HP/LP Flare:

Total Air Flow: 1599580 kg/h;

LLP Flare:

Total Air Flow: 476875 kg/h.

The heat radiation levels reached at the critical receptor points are the following:

- Flare Stack Base: 7.620 kW/m^2
- Plant Boundary: 1.840 kW/m^2

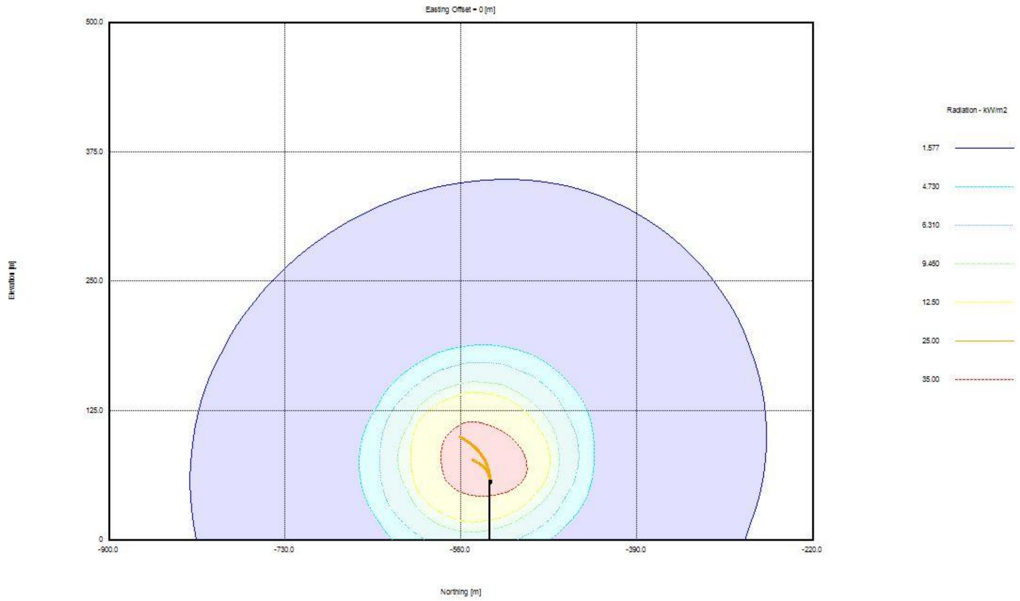

Figure 10: Heat Radiation Contours – Vertical View (Sensitivity Case 3)

The result shows that the increase of the air stream flowrate at the flare tip, in order to reach the 100% smokeless operation condition, would reduce the heat radiation levels reached both at the Flare Stack Base, and at the Plant Boundary, in comparison with the Base Case. In particular, at the Plant Boundary the value of the heat radiation is significantly lower and very close to the acceptable level of 1.58 kW/m^2.

7.4 Implementation of Assisting Steam Stream (20% smokeless operation) (Sensitivity Case 4)

As a next step, the possibility to modify the assisting fluid from air to steam, in order to reach exactly the 20% smokeless operation, has been evaluated.

The following total steam flow rates have been considered:
HP/LP Flare:
Total Air Flow: 319916 kg/h;

LLP Flare:
Total Air Flow: 95375 kg/h.

The heat radiation levels reached at the critical receptor points are the following:
- Flare Stack Base: 8.724 kW/m^2
- Plant Boundary: 1.979 kW/m^2

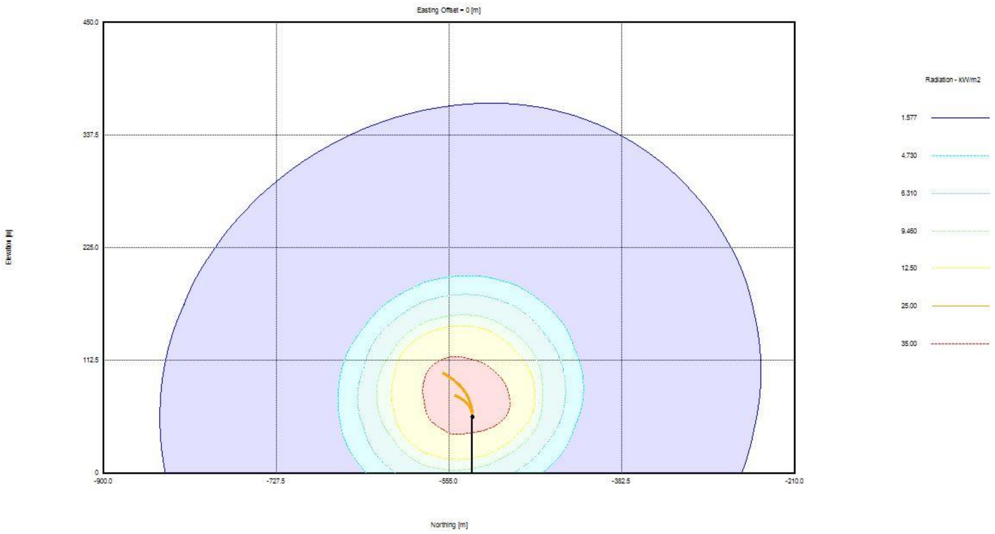

Figure 11: Heat Radiation Contours – Vertical View (Sensitivity Case 4)

The result shows that the implementation of assisting steam stream for 20% smokeless operation condition would reduce the heat radiation levels reached both at the Flare Stack Base, and at the Plant Boundary in comparison with the Base Case and to the Sensitivity Case 2. The steam stream addition would allow reaching a more efficient condition in terms of emissions than the addition of air stream.

7.5 Implementation of Sonic Flare Tip (Sensitivity Case 5)

One of the sensitivity cases examined in the study was the possibility to install a sonic flare tip instead of a generic tip pipe.

The sonic flare tip would allow to reach a Mach number equal to 1 at the exit of the flare tip causing an increase of the exit gas velocity from the stack.

In more detail, the following results have been obtained for this Sensitivity Case 5:

HP/LP Flare

Tip Exit Velocity: 364.1 m/s;

Mach Number: 1;

Backpressure at Stack Base: 0.823.

LLP Flare:

Tip Exit Velocity: 308.4 m/s;

Mach Number: 1;

Backpressure at Stack Base: 0.846.

The heat radiation levels reached at the critical receptor points are the following:

- Flare Stack Base: 4.746 kW/m^2 (acceptable);
- Plant Boundary: 1.526 kW/m^2 (acceptable).

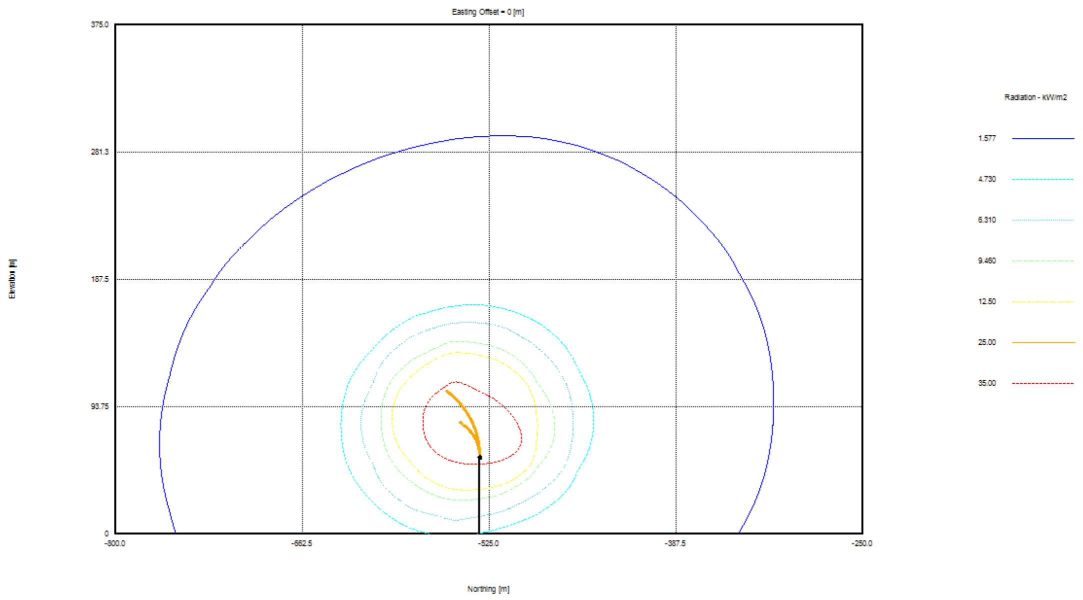

Figure 12: Heat Radiation Contours – Vertical View (Sensitivity Case 5)

The result shows the importance of the flare tip type, especially in continuous flaring: by implementing a relatively small modification of changing the flare tip, the radiation levels would be acceptable both at the Flare Stack Base and at the Plant Boundary.

7.6 Installation of an Additional Flare (Sensitivity Case 6)

The next Sensitivity Case examined, was the possibility to add an additional flare stack, identical to the existing one described in the Base Case, with both HP/LP and LLP headers.

This configuration allows to have the following operation and maintenance conditions:

- Normal operation – both flare stacks in operation (with 50% capacity each);
- Maintenance – one flare in operation, second in maintenance.

With this flaring system in place, the flared stream is split between the two flares. This causes a reduction of the exit gas velocity from the two stacks. In particular, the following results have been obtained for this Sensitivity Case 6:

HP/LP Flare

Tip Exit Velocity: 86.2 m/s;

Mach Number: 0.2368;

Backpressure at Stack Base: 0.045.

LLP Flare:

Tip Exit Velocity: 50.0 m/s;

Mach Number: 0.1622;

Backpressure at Stack Base: 0.033.

The heat radiation levels reached at the critical receptor points are the following:

- Flare Stack Base: 6.493 kW/m^2 (acceptable);
- Plant Boundary: 1.706 kW/m^2 (still not acceptable, higher than 1.58 kW/m^2, but lower than the Base Case).

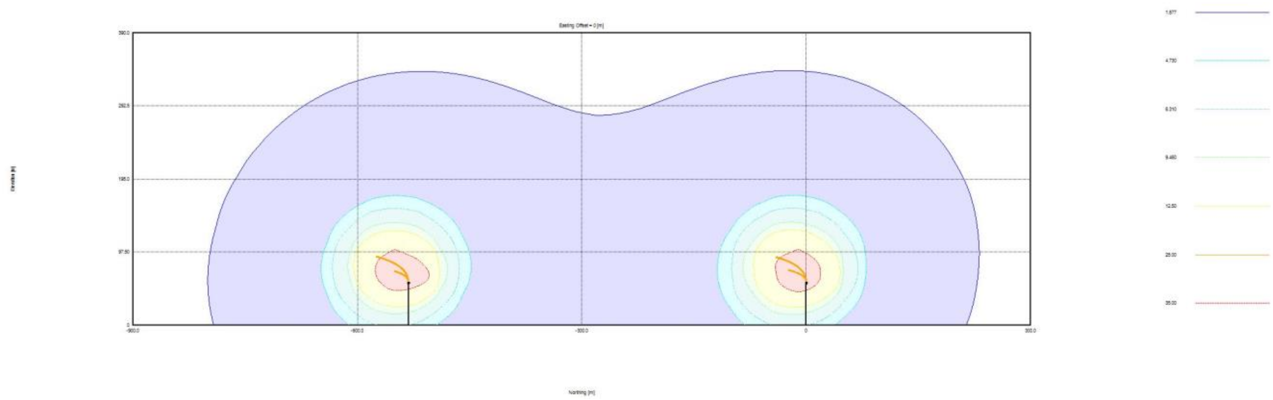

Figure 13: Heat Radiation Contours – Vertical View (Sensitivity Case 6)

The solution would help to significantly reduce the radiation levels close to an acceptable limit; we notice reduction of radiation at the Flare Stack Base and significant reduction close to the acceptable limit of 1.58 kW/m^2 at the Plant Boundary.

Furthermore, it would solve a number of maintenance issues for the plant, especially for the nearby equipment -such as the blowers-. If one flare would have to be shutdown to maintain nearby equipment, the other one would still be able to operate in order not to have to shut-down the plant.

7.7 Installation of an Additional Flare and Increase of the Height of Both Existing and New Flare Stacks (Sensitivity Case 7)

The possibility to add an additional flare stack and to increase the height of both the existing and the new flare stacks to 70 m has been considered as a Sensitivity Case, in order to evaluate the effects of the combination of these two design proposals.

Similar to Sensitivity Case 6, the flared stream is split between the two flares. This causes a reduction of the exit gas velocity from the two stacks. The results are the same with Sensitivity Case 6, in terms of tip exit velocity, Mach Number and Backpressure at Stack Base.

The heat radiation levels reached at the critical receptor points are the following:

- Flare Stack Base: 5.215 kW/m^2
- Plant Boundary: 1.686 kW/m^2

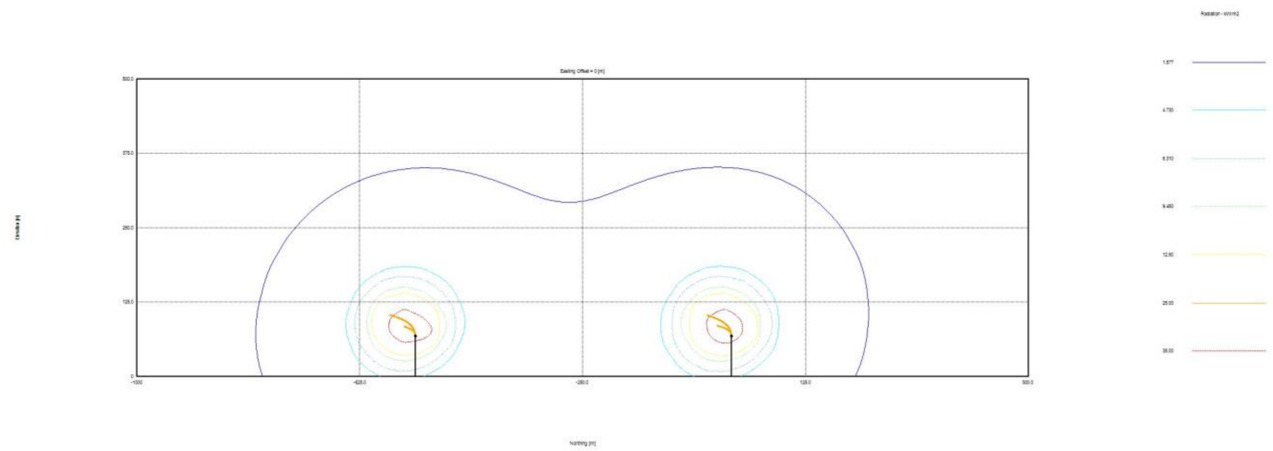

Figure 14: Heat Radiation Contours – Vertical View (Sensitivity Case 7)

The proposed combined design solution would help to significantly reduce the radiation levels close to an acceptable limit. We notice reduction of radiation at the Flare Stack Base and significant reduction close to the acceptable limit of 1.58 kW/m^2 at the Plant Boundary.

7.8 Installation of an Additional Flare and Installation of Sonic Tip for Both Existing and New Flare (Sensitivity Case 8)

The possibility to add an additional flare stack and to install a sonic tip for both the existing and the new flare stacks has been considered as Sensitivity Case 7, in order to evaluate the effects of the combination of these two design solutions

In addition, similar to Sensitivity Case 6, the flared stream is split between the two flares. This causes a reduction of the exit gas velocity from the two stacks. In addition, the installation of a sonic tip allows to reach a Mach number equal to 1 at the exit of the flare tip. The following results have been obtained for this Sensitivity Case 8:

HP/LP Flare

Tip Exit Velocity: 364.1 m/s;

Mach Number: 1;

Backpressure at Stack Base: 0.823.

LLP Flare:

Tip Exit Velocity: 308.4 m/s;

Mach Number: 1;

Backpressure at Stack Base: 0.846.

The heat radiation levels reached at the critical receptor points are the following:

- Flare Stack Base: 4.567 kW/m^2
- Plant Boundary: 1.387 kW/m^2

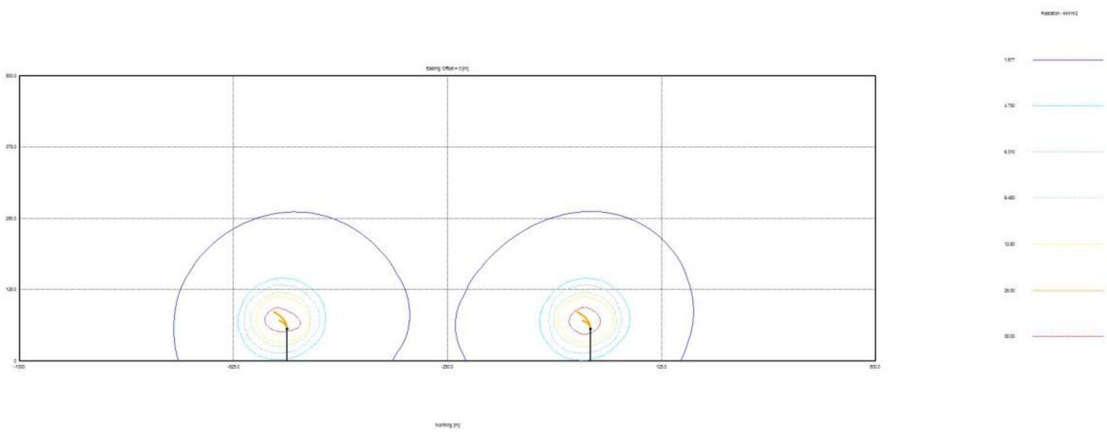

Figure 15: Heat Radiation Contours – Vertical View (Sensitivity Case 8)

This proposed combined design solution would help to significantly reduce the radiation levels close at an acceptable limit. We notice reduction of radiation at the Flare Stack Base and significant reduction lower than the acceptable limit of 1.58 kW/m^2 at the Plant Boundary.

7.9 Absence of Assisting Air Stream (Comparison Case)

For sake of completeness, the case of “Absence of Assisting Air Stream” has also been evaluated, in order to demonstrate the difference in results in comparison with the -emission changing- Sensitivity Cases conducted as part of this study.

The results in terms of heat radiation levels reached at the critical receptor points are the following:

- Flare Stack Base: 9.419 kW/m^2
- Plant Boundary: 2.519 kW/m^2

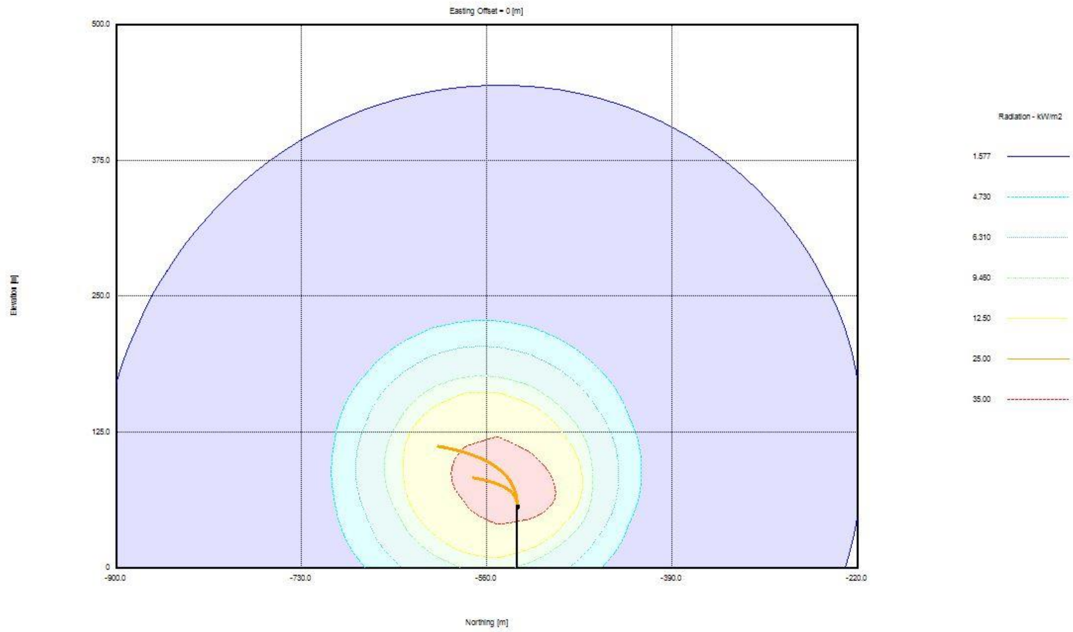

Figure 16: Heat Radiation Contours – Vertical View (Comparison Case 1)

As expected, absence of assisting air stream represents an unacceptable scenario in terms of emissions as heat radiation limits are reached both at the Flare Sack Base and at the Plant Boundary. These values are higher than all other cases, including the Base Case and it is therefore not suggested as an emission reduction solution.

8. Summary of Results and Conclusions

The current study has investigated a realistic scenario of continuous gas flaring. Initially, the Base Case scenario was analysed, followed by eight (8) sensitivity analyses intended to achieve emission reduction from the flare.

The flare system that was considered as the Base Case, is constituted by two flare systems: HP/LP (High Pressure/Low Pressure) Flare and LLP (Low Low Pressure) Flare. These two flares are arranged on the same flare stack. The results in terms of heat radiation contours show that the heat radiation level reached at the base of the flare stack is acceptable, according with the criteria defined by API 521. However, the heat radiation level reached at the plant boundary exceeds the acceptable value. The sterile area exceeds the plant boundary and this condition is not acceptable for the safety of the public.

In addition, the results for flammable gas and toxic gas (H_2S) dispersion, in case of Flame Out, show that the dangerous threshold values (1/2 LFL for flammable gas and IDLH and LCLo for toxic gas) do not reach the ground level. Therefore, it was no further design suggestions were made in this Study for Flame Out cases. As a general recommendation the provision of gas detectors is recommended for the operators of the subject plant. Therefore, of toxic or flammable gas alarm, operators would be able to act by donning a mask and evacuating the area upwind and as per to plant's Emergency Evacuation Procedure.

In order to reduce the heat radiation level reached on the ground, at the critical receptor points (in particular at the plant boundary), the effects of the eight (8) sensitivity cases have been evaluated.

- Sensitivity Case 1: Increase of Flare Height.
- Sensitivity Case 2: Adjustment of Assisting Air Stream Flowrate in order to reach the 20% smokeless operation condition.
- Sensitivity Case 3: Increase of Assisting Air Stream in order to reach the 100% smokeless operation.
- Sensitivity Case 4: Implementation of Assisting Steam Stream for 20% smokeless operation condition.
- Sensitivity Case 5: Implementation of Sonic Flare Tip.
- Sensitivity Case 6: Installation of an Additional Flare.
- Sensitivity Case 7: Installation of an Additional Flare and Increase of the Height of Both Existing and New Flare Stacks.
- Sensitivity Case 8: Installation of an Additional Flare and Installation of Sonic Tip for Both Existing and New Flare.

In Sensitivity Case 1, the increase of the flare stack height would allow to reduce slightly the heat radiation level reached at the plant boundary. This solution could have significant cost, since very high structures require special support systems. Furthermore, the relatively small improvement in the radiation value would not justify the expense.

In Sensitivity Case 2, the adjustment of the assist fluid flow ratio (air stream) in order to reach the 20% smokeless operation condition does not represent a significant increase of safety, since the results in terms of heat radiation levels reached both at the Flare Stack Base, and at the Plant Boundary are worse than the Base Case. This also means that the Base Case represents already smokeless condition better than the 20%.

In Sensitivity Case 3, the increase of the assist fluid flow ratio (air stream) in order to reach the100% smokeless operation would allow to decrease significantly the heat radiation level reaching the Plant Boundary, even if the acceptable value is still exceeded, but represents a not very cheap solution considering the installation of blowers with very high capacity at the flare stack base. They would need to be located in an adequate position and protected with appropriate shelters from the heat radiation emitting from the flare. The expense for supporting this option would probably be not justified.

In Sensitivity Case 4, the implementation of assisting steam stream for 20% smokeless operation condition would allow to decrease significantly the heat radiation level reaching the Plant Boundary, even if the acceptable value is still exceeded. The increase in personnel and public safety is higher compared to the Base Case and to Sensitivity Case 2, and it is lower compared to Sensitivity Case 3. However, this solution could represent an interesting one, if a steam line is already present in the plant. On the other hand, if the steam production system would need to be implemented in the plant, this solution would become more expensive.

The implementation of a sonic flare tip (Sensitivity Case 5) could be a reasonable solution, considering the construction activities that would be done (e.g. by helicopter) for the substitution of the existing generic pipe tip. This solution would allow to reduce drastically the heat radiation level reached at the plant boundary and also to maintain the sterile area inside the plant boundary limits, without impact on the public.

The installation of an additional flare, identical to the existing one described in the Base Case, (Sensitivity Case 6) would allow to reduce the heat radiation level reached at the plant boundary, even if the acceptable value is still slightly exceeded. This solution would be expensive, however, it has also an additional advantage: the significantly improved maintainability. Having two flares, would solve a number of maintenance issues for the plant, especially for the nearby equipment -such as the blowers-. If one flare would have to be shut-down the other one would operate in order not to shut-down the plant. In order to establish the position of the new flare stack, the heat radiation level at the flare stack top of the flare under maintenance would need to be evaluated and it should not exceed a threshold value acceptable for the maintenance activities.

The combination of the studied design solutions has also been evaluated (Sensitivity Cases 7 and 8). Sensitivity Case 7 studies the effects of an additional flare together with height addition for both flares. Sensitivity Case 8 presents an overall better solution with the installation of an additional flare and the implementation of sonic flare tip for both existing and new flares. The heat radiation results produced are acceptable at all critical receptor points, i.e. Flare Stack Base and Plant Boundary. This solution (Sensitivity Case 8), although probably the most expensive in terms of implementation, has a combination of the most advantages from the proposed options, since it permits to avoid any heat radiation impact to the public and at the same time offers significant improvement to the maintainability of the plant.

For sake of completeness, the case of “Absence of Assisting Air Stream (Comparison Case)” has also been evaluated, in order to demonstrate the difference in results in comparison with the -emission changing- Sensitivity Cases conducted as part of this study.

As a conclusion, if a simple solution would need to be proposed for emission reduction, this would be Sensitivity Case 5, i.e. the implementation of sonic flare tip. The overall best solution though is the one presented by Sensitivity Case 8 -i.e. two (2) flare stacks with sonic flare tips-, which results in the ultimate improvement in terms of heat radiation reduction.

References

[1] Flaresim Software, developed by Softbits, Version 5.

[2] Phast Software, developed by DNV, Version 6.7.