Knauf Insulation

Assessment of Sulphur Dioxide Emissions from Furnace Stack using Inverse Modelling

Cwmbran Installation

June 2011

AMEC Environment & Infrastructure UK Limited

Report for

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Checklist

Item	✓/✗	Reason for Omission
Location Map	✓	
Site Plan	✓	
List of pollutants modelled and relevant air quality guidelines	✓	
Details of modelled scenarios	✓	
Details of relevant ambient concentrations used	✓	
Model description and justification	✓	
Special model treatments used	✓	
Table of emission parameters used	✓	
Details of modelled domain and receptors	✓	
Details of meteorological data used, including origin, and justification	✓	
Details of terrain treatment	✓	
Details of buildings treatment	✓	
Details of modelling wet/dry deposition	✓	
Sensitivity analysis	✓	
Assessment of impacts	✓	
Model input files	✓	

Abbreviations

AQAP	Air Quality Action Plan
AQMA	Air Quality Management Area
AQO	Air Quality Objective
AQS	Air Quality Standard
AURN	Automatic Urban and Rural Network
CERC	Cambridge Environmental Research Consultants
CBL	Convective Boundary Layer
Defra	Department for Environment, Food and Rural Affairs
EAL	Environmental Assessment Level
ELV	Emission Limit Value
EPAQS	Expert Panel on Air Quality Standards
EPR	Environmental Permitting Regulations 2010
EU	European Union
IPPC	Integrated Pollution Prevention and Control
LAQM	Local Air Quality Management
LV	Limit Value
PC	Process Contribution
PEC	Predicted Environmental Concentration (=PC + background)
WHO	World Health Organisation

Contents

1. Introduction

1.1 Background, Aims and Objectives

Knauf Insulation Ltd ('Knauf') are considering proposals to alter the composition of raw materials used to manufacture glass fibre wool at the Cwmbran installation, namely increasing the use of recycled cullet. Knauf consider that this change is likely to increase the sulphur content of the raw material which, when melted in the installation's furnace, will lead to an increase the concentration of sulphur dioxide (SO_2) in the furnace off-gas.

Consequently, Knauf have commissioned AMEC Environment and Infrastructure UK Limited ('AMEC') to undertake a detailed dispersion modelling assessment to ascertain at what concentration of off gases in the furnace stack are breaches of the ambient SO_2 air quality standards and objectives (AQS/AQOs) likely.

The assessment utilises data recorded during recent stack emission monitoring surveys to define key model input parameters, including efflux temperature and volumetric flow, and uses inverse modelling to ascertain equivalent SO_2 emission rates (and, hence, stack concentrations) that would produce incremental increases in the contributions to the ambient SO_2 and compares these against the AQS/AQOs.

The dispersion of emissions in this assessment is predicted using an appropriate dispersion model, with results presented in tabular and graphical form. The assessment considers short and long-term effects in relation to the air quality standards set in legislation and in Government and international guidance.

1.2 Site Description

The site is located at NGR: ST 299 978 just to the north of Cwmbran, Gwent, South Wales and situated in the Afon Lwyd valley within a light industrial area. The wider area comprises the urban centres of Pontypool to the north, Cwmbran to the south, with rural areas dominating the higher land to the east and the immediate west of the valley.

The installation produces a light density glass mineral roll and loose fibre products for use as thermal insulation material. The process produces glass mineral wool product in a two stage process. The first stage involves melting glass in a furnace and then processing the molten glass into fibres. The fibres are then bound together in a forming process to give a glass mineral wool mat with a nominal thickness ranging from 80mm to 200mm. Following the introduction of a new process line, an unbound product, known as white wool, is produced for use as a cavity wall insulator.

Emissions to atmosphere arise from both stages of the process. Emissions from the melting stage result from combustion products generated in the glass furnace. Waste gas flows from the furnace are past through an electrostatic precipitator abatement plant prior to being emitted to atmosphere via a 70m stack.

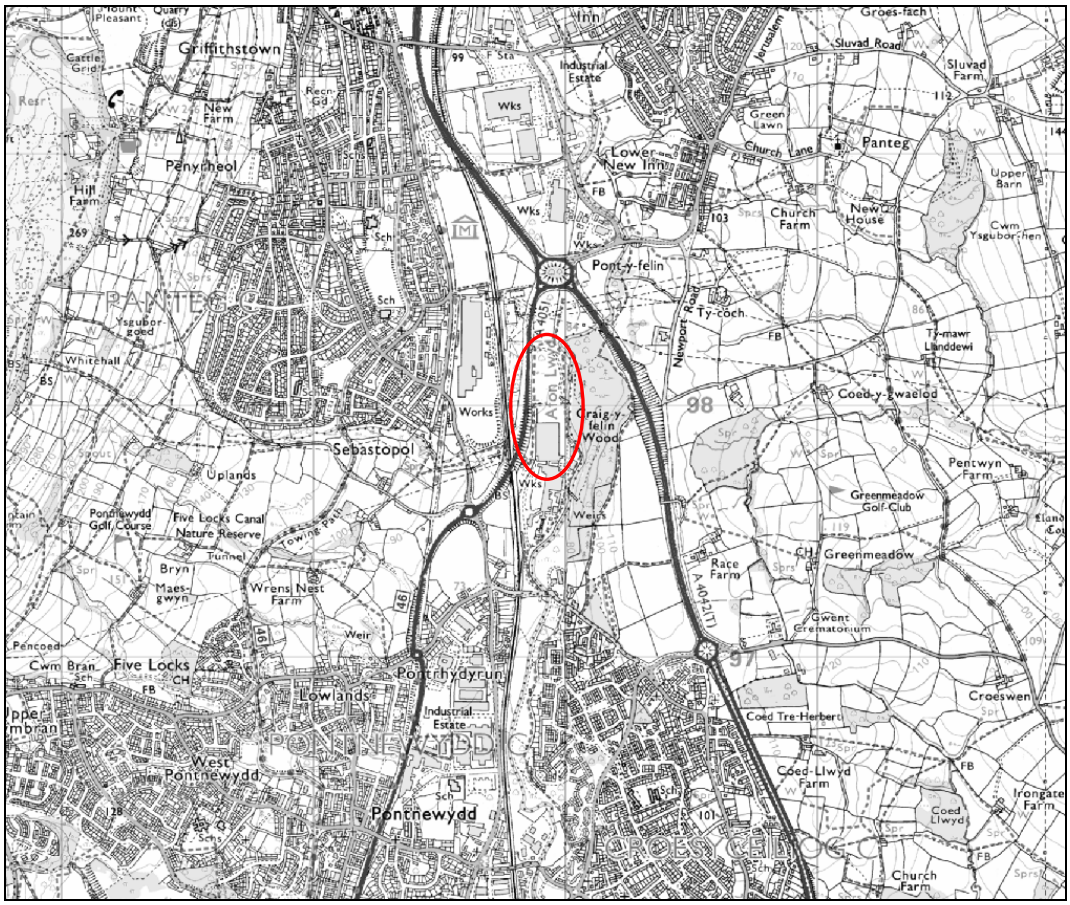
Off-gas formed during the glass mineral wool roll forming stage consists of particulates and volatilised organic materials used in the binder. This gas stream is passed through a wet scrubber before being emitted to atmosphere via an 85m stack. The scrubber liquor is recycled within the wash water circuit.

Air extracted from the white wool process line is passed through a water pre-scrubber and scrubber for particulate removal before being emitted to atmosphere via a 50m stack. As the product is unbound, the gas stream does not contained volatilised gaseous compounds generated during the glass mineral wool roll forming stage.

Emissions of SO_2 only occur from the furnace stack and, therefore,, for this assessment only the emissions from the furnace stack have been considered.

Figure 1.1 provides a site location map, indicating the location of the site in relation to the local area.

Figure 1.1 Site Location Map



1.3 Sources of Information

The information used to assess air quality includes:

- Process and emissions data provided by Knauf Insulation Ltd;
- Site layout from Knauf Insulation Ltd and Ordnance Survey mapping;
- Baseline air quality data from surveys undertaken by Government bodies, Local Authorities and third parties;
- Ordnance Survey (OS) maps of the local area; and
- Meteorological data supplied by Atmospheric Dispersion Modelling Ltd.

1.4 Report Structure

The remainder of the report is set out as follows:

Table 1.1 Report Structure

Section	Aims and Objectives
Section 2	Describes the dispersion model, assessment methodology, model inputs and assumptions used in the assessment, and details the ambient air quality in the area
Section 3	Details the assessment criteria
Section 4	Presents an assessment of the potential air quality impacts arising from the site emissions
Section 5	Contains a summary and conclusions of the assessment

2. Assessment Methodology

2.1 The Dispersion Model

The model used in this assessment is the ADMS 4.2 advanced atmospheric dispersion model that has been developed and validated by Cambridge Environmental Research Consultants (CERC). The model has been used extensively throughout the UK for regulatory compliance purposes and is accepted as an appropriate air quality modelling tool by the Environment Agency and local authorities.

ADMS 4.2 parameterises stability and turbulence in the atmospheric boundary layer (ABL) by the Monin-Obukhov length and the boundary layer depth. This approach allows the vertical structure of the ABL to be more accurately defined than by the stability classification methods of earlier dispersion models such as R91 or ISCST3. In ADMS, the concentration distribution follows a symmetrical Gaussian profile in the vertical and crosswind directions in neutral and stable conditions. However, the vertical profile in convective conditions follows a skewed Gaussian distribution to take account of the inhomogeneous nature of the vertical velocity distribution in the Convective Boundary Layer (CBL).

A number of complex modules, including the effects of plume rise, complex terrain, coastlines, concentration fluctuations, radioactive decay and buildings effects, are also included in the model, as well as the facility to calculate long-term averages of hourly mean concentration, dry and wet deposition fluxes, and percentile concentrations, from either statistical meteorological data or hourly average data.

A range of input parameters is required including, among others, data describing the local area, meteorological measurements and emissions data. The data used in modelling the emissions are given in the following sections of this chapter.

2.2 Inverse Modelling and Process Emissions

The predominate application of dispersion models is to predict ambient concentrations (C_a) at local receptor locations from a known stack concentration (C_s), that is, if all other parameters remain constant, the ambient concentration is a direct function of the stack concentration, i.e.,

$$C_a = f(C_s) \tag{1}$$

In numerical problem solving, this approach is often known as forward modelling. Inverse modelling, on the other hand, attempts to relate the model input parameters to the data that is observed or predicted. Taking the equation above, the inverse solution can be written as:

$$C_s = f(C_a) \tag{2}$$

Thus, for a known ambient concentration (for example, the pertinent Air Quality Standard/Objective (AQS/AQO) or fractions thereof), inverse modelling allows the equivalent stack concentration that would produce that a particular ambient concentration to be determined.

In this instance, the dispersion model has been configured with a unitary emission rate from the furnace stack to establish a 'dispersion factor'. Utilisation of this dispersion factor with the relevant percentage of the AQS/AQO of interest allows the equivalent stack emission concentration to be determined.

Calculations are performed for each of the SO_2 AQS/AQO (i.e., the 15-minute mean AQO, and the 1-hour and 24-hour mean AQS) at the specific human receptor experiencing the maximum predicted process contribution from the furnace stack. Equivalent stack emission concentrations are provided in 1% increments of each AQS/AQO from 1%-100% of the AQS/AQO.

Table 2.1 details the physical and process stack parameters for the furnace stack. This data has been derived from the average of three runs undertaken during a recent emissions monitoring survey on the furnace stack (NWSS, 2011).

Table 2.1 Furnace Stack Physical and Process Parameters

Parameter	Value
Location (X)	329909
Location (Y)	197586
Stack Height (m)	70
Stack Diameter (m)	0.99
Volume Flow at Discharge Conditions (Am^3s^{-1})	14.0
Volume Flow at Reference Conditions (Nm^3s^{-1})	7.4
Efflux Temperature (°C)	200

2.3 Meteorology

For meteorological data to be suitable for dispersion modelling purposes, a number of meteorological parameters need to be measured on an hourly basis. These parameters include wind speed, wind direction, cloud cover and temperature. There are only a limited number of sites where the required meteorological measurements are made. The year of meteorological data that is used for a modelling assessment can also have a significant effect on ground level concentrations.

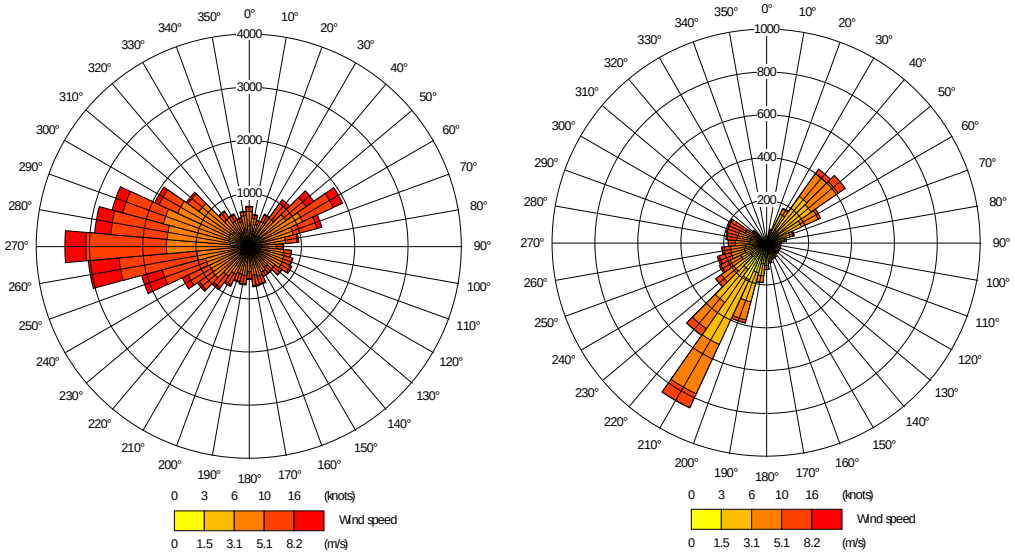
Rhoose meteorological station is situated at Cardiff International Airport and is the nearest meteorological station for which data in a format suitable for the model is available. The use of Rhoose data has been approved by the Environment Agency during previous modelling studies at the site. However, it is known that, due to local terrain influences, the prevailing wind direction in the local area is from the south/south-south-west, whereas data from Rhoose indicates a prevailing westerly wind.

It is a requirement for dispersion modelling air quality impact assessments to utilise a minimum of five years of hourly sequential data, modelled individually to give a range of predictions[1]. Whilst on-site wind speed and direction data is available from on-site instrumentation at the Cwmbran installation, five years of data is not available.

Consequently, this assessment utilises meteorological data recorded at Rhoose during the period 2006-2010 but assesses the sensitivity of model predictions by comparing output using 2009-2010 wind speed and direction data from the on-site instrumentation; these being the only years where a complete annual data set is available.

Figure 2.1 presents a wind rose of the 2009 Rhoose data and a composite wind rose of the available on-site data recorded during 2009 for comparison.

Figure 2.1 Comparison of 2009 Rhoose (Left) and On-site Weather Station (Right) Wind Rose Data



2.4 Surface Characteristics

The predominant surface characteristics and land use in a model domain have an important influence in determining turbulent fluxes and, hence, the stability of the boundary layer and atmospheric dispersion. Factors pertinent to this determination are detailed below.

2.4.1 Surface Roughness

Roughness length, z_0, represents the aerodynamic effects of surface friction and is physically defined as the height at which the extrapolated surface layer wind profile tends to zero. This value is an important parameter used by meteorological pre-processors to interpret the vertical

[1] http://www.environment-agency.gov.uk/business/regulation/38791.aspx

profile of wind speed and estimate friction velocities which are, in turn, used to define heat and momentum fluxes and, consequently, the degree of turbulent mixing.

The surface roughness length is related to the height of surface elements; typically, the surface roughness length is approximately 10% of the height of the main surface features. Thus, it follows that surface roughness is higher in urban and congested areas than in rural and open areas. Oke (1987) and CERC (2003) suggest typical roughness lengths for various land use categories (Table 2.2).

Table 2.2 Typical Surface Roughness Lengths for Various Land Use Categories

Type of Surface	z_0 (m)
Ice	0.00001
Smooth snow	0.00005
Smooth sea	0.0002
Lawn grass	0.01
Pasture	0.2
Isolated settlement (farms, trees, hedges)	0.4
Parkland, woodlands, villages, open suburbia	0.5-1.0
Forests/cities/industrialised areas	1.0-1.5
Heavily industrialised areas	1.5-2.0

Increasing surface roughness increases turbulent mixing in the lower boundary layer. This can often have conflicting impacts in terms of ground level concentrations:

- The increased mixing can bring portions of an elevated plume down towards ground level, resulting in increased ground level concentrations closer to the emission source; however; and
- The increased mixing increases entrainment of ambient air into the plume and dilutes plume concentrations, resulting in reduced ground level concentrations further downwind from an emission source.

The overall impact on ground level concentration is, therefore, strongly correlated to the distance and orientation of a receptor from the emission source.

2.4.2 Surface Energy Budget

One of the key factors governing the generation of convective turbulence is the magnitude of the surface sensible heat flux. This, in turn, is a factor of the incoming solar radiation. However, not all solar radiation arriving at the Earth's surface is available to be emitted back to atmosphere in the form of sensible heat. By adopting a surface energy budget approach, it can be identified that, for fixed values of incoming short and long wave solar radiation, the surface sensible heat flux is inversely proportional to the surface albedo and latent heat flux.

The surface albedo is a measure of the fraction of incoming short-wave solar radiation reflected by the Earth's surface. This parameter is dependent upon surface characteristics and varies throughout the year. Oke (1987) recommends average surface albedo values of 0.6 for snow covered ground and 0.23 for non-snow covered ground, respectively.

The latent heat flux is dependent upon the amount of moisture present at the surface. The Priestly-Taylor parameter can be used to represent the amount of moisture available for evaporation:

$$\alpha = \frac{1}{S(B+1)}$$

Where:

α = Priestly-Taylor parameter (dimensionless)

$$S = \frac{s}{s+\gamma}$$

$$s = \frac{de_s}{dT}$$

e_s = Saturation specific humidity (kg H_2O / kg dry air)

T = Temperature (K)

$$\gamma = \frac{c_{pw}}{\lambda}$$

c_{pw} = Specific heat capacity of water (kJ kg^{-1} K^{-1})

λ = Specific latent heat of vaporisation of water (kJ kg^{-1})

B = Bowen ratio (dimensionless)

Areas where moisture availability is greater will experience a greater proportion of incoming solar radiation released back to atmosphere in the form of latent heat, leaving less available in the form of sensible heat and, thus, decreasing convective turbulence. Holstag and van Ulden (1983) suggest α values of 0.45 and 1.0 for dry grassland and moist grassland respectively.

2.4.3 Selection of Appropriate Surface Characteristic Parameters for the Site

A detailed analysis of the effects of surface characteristics on ground level concentrations by Auld *et al.* (2002) led them to conclude that, with respect to uncertainty in model predictions:

> *"…the energy budget calculations had relatively little impact on the overall uncertainty"*

In this regard, it is not considered necessary to vary the surface energy budget parameters spatially or, temporally, and annual averaged values have been adopted throughout the model domain for this assessment.

As snow covered ground is only likely to be present for a small fraction of the year, the surface albedo of 0.23 for non-snow covered ground advocated by Oke (1987) has been used whilst the model default α value of 1.0 has also been retained.

From examination of 1:10,000 Ordnance Survey maps, it can be seen that within the immediate vicinity of the site, land use is predominately mixed industrial with areas of residential housing beyond, and with banks of trees to the immediate east and north-west of the installation. Consequently, a composite surface roughness length of 1m has been used to take account of the respective land use categories in the model domain; this value is consistent with previous modelling studies undertaken for the installation.

2.5 Buildings

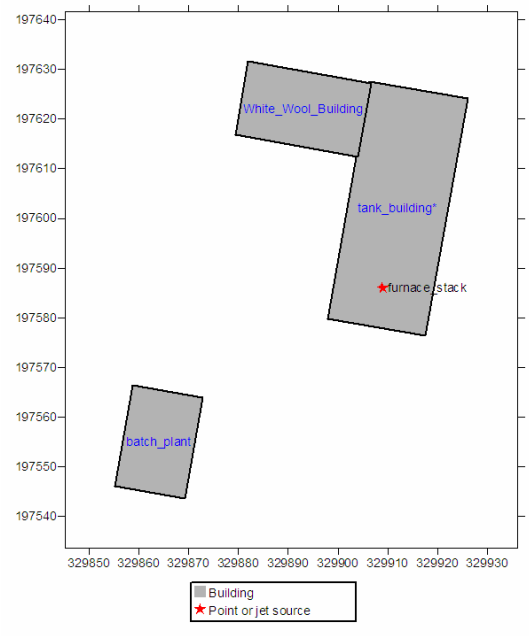
Any large, sharp-edged object has an impact on atmospheric flow and air turbulence within the locality of the object. This can result in maximum ground level concentrations that are significantly different (generally higher) from those encountered in the absence of buildings. The building 'zone of influence' is generally regarded as extending a distance of 5L (where L is the lesser of the building height or width) from the foot of the building in the horizontal plane and three times the height of the building in the vertical plane.

The following structures, as detailed in Table 2.3 and Figure 2.2, have been identified as causing possible disturbance to any emitted plume and, therefore, included in the model.

Table 2.3 Buildings Modelled

Building	X (m)	Y (m)	Height (m)	Length (m)	Width (m)	Angle (°)
Tank Building	329912	197602	33.8	48.5	20	10
Batch Plant	329864	197555	44	20.5	14.2	10
White Wool Building	329893	197622	14	15	25.5	10

Figure 2.2 Buildings Visualisation



2.6 Terrain

The concentrations of an emitted pollutant found in elevated, complex terrain differ from those found in simple level terrain. There have been numerous studies on the effects of topography on atmospheric flows. A summary of the main effects of terrain on atmospheric flow and dispersion of pollutants are summarised below:

- Plume interactions with windward facing terrain features;
  - Plume interactions with terrain features whereby receptors on hills at a similar elevation to the stack experience elevated concentrations.
  - Direct impaction of the plume on hill slopes in stable conditions.
  - Flow over hills in neutral conditions can experience deceleration forces on the upwind slope, reducing the rate of dispersion and increasing concentrations.
- Plume interactions with lee sides of terrain features; and
  - Regions of recirculation behind steep terrain features can rapidly advect pollutants towards the ground culminating in elevated concentrations.
  - Releases into the lee of a hill in stable conditions can also be recirculated, resulting in increased ground level concentrations.
- Plume interactions within valleys.
  - Releases within steep valleys experience restricted lateral dispersion due to the valley sidewalls. During stable overnight conditions, inversion layers develop within the valley essentially trapping all emitted pollutants. Following sunrise

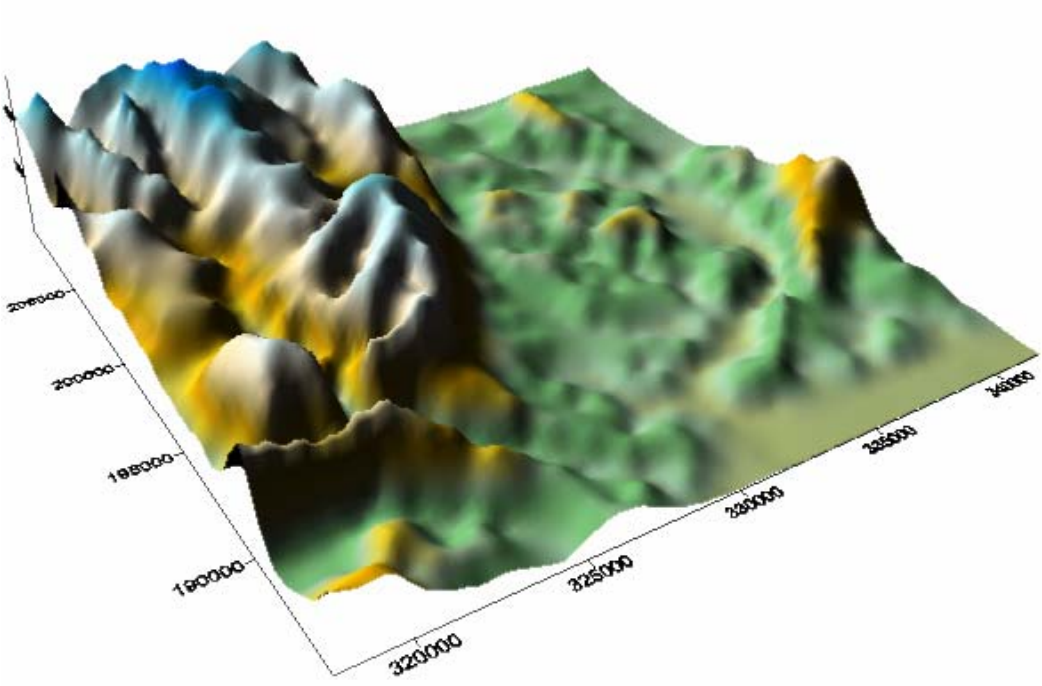
and the erosion of the inversion, elevated ground level concentrations can result during fumigation events.

- Convective circulations in complex terrain due to differential heating of the valley side walls can lead to the impingement of plumes due to crossflow onto the valley sidewalls and the subsidence of plume centrelines, both having the impact of increasing ground level concentrations.

These effects are most pronounced when the terrain gradients exceed 1 in 10 i.e., a 100m change in elevation per 1km step in the horizontal plane. The gradients surrounding the immediate site do exceed this criterion and, consequently, digitally mapped terrain data procured from emapsite has been included in the model.

Figure 2.3 provides a shaded relief map of terrain within the model domain; the installation is located at the centre of the figure.

Figure 2.3 Terrain Visualisation



2.7 Modelled Domain and Receptors

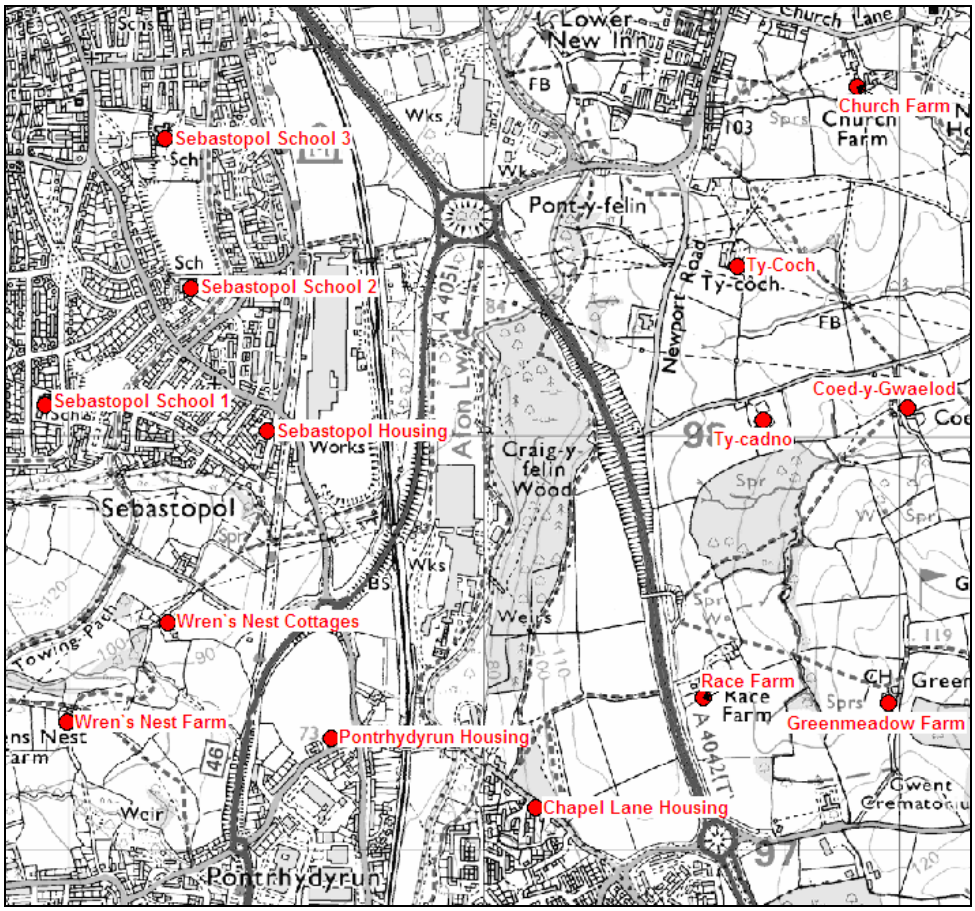
2.7.1 Human Receptors

The receptors considered were chosen based on locations where people may be located and judged in terms of the likely duration of their exposure to pollutants and proximity to the site. Details of the locations of human receptors are given in Table 2.4 and Figure 2.4 below.

Table 2.4 Details of Modelled Human Receptors

ID	Receptor Name	Easting (m)	Northing (m)
1	Sebastopol Housing	329475	198012
2	Sebastopol School 1	328938	198075
3	Sebastopol School 2	329291	198357
4	Sebastopol School 3	329226	198718
5	Wren's Nest	329233	197551
6	Wren's Nest Farm	328989	197311
7	Ty-coch	330608	198410
8	Ty-cadno	330669	198040
9	Coed-y-gwaelod	331018	198068
10	Church Farm	330895	198846
11	Race Farm	330526	197371
12	Pontrhydyrun Housing	329629	197270
13	Chapel Lane	330122	197102
14	Greenmeadow Farm	330970	197355

Figure 2.4 Location of Modelled Human Receptors



2.7.2 Ecological Receptors

The Environment Agency's Horizontal Guidance Note H1 Annex (f) requires detailed dispersion modelling to be carried out based on local receptors. With regard to ecological receptors page 12 of H1 Annex (f) states:

> *"Note that conservation sites need only be considered where they fall within set distances of the activity:*
>
> - *Special Protection Areas (SPAs), Special Areas of Conservation (SACs) or Ramsar sites within 10km of the installation (or 15km coal or oil-fired power station)*
> - *Sites of Special Scientific Interest (SSSIs), National Nature Reserves (NNRs), Local Nature Reserves (LNRs), local wildlife sites and ancient woodland within 2km of the location.*
>
> *Some larger emitters may be required to screen to 10km or 15km for SSSIs."*

Following the above guidance the following ecological receptors have been included in the assessment.

Table 2.5 Details of Modelled Ecological Receptors

Name	Easting (m)	Northing (m)
River Usk SAC	338492	196729

2.8 Existing Ambient Data

2.8.1 Continuous Monitoring Data

Defra maintains a continuous air quality monitoring network throughout England and Wales; the Automatic Urban and Rural Network (AURN). An AURN station is located in Cwmbran, approximately 3km south of the installation. However, the station only monitors oxides of nitrogen (NO_x), ozone (O_3) and particulates (PM_{10}) and, consequently, would not provide relevant data for this assessment.

2.8.2 Defra Mapped Background Concentrations

Defra, through its contractor AEA Technology plc, maintains a nationwide model (the Pollution Climate Mapping (PCM) model) of existing and future background air quality concentrations at a 1 km grid square resolution. The data includes annual average concentration estimates for NO_x, NO_2, PM_{10} $PM_{2.5}$ CO, SO_2 and benzene. The PCM model is semi-empirical in nature: it uses emissions data from the national atmospheric emissions inventory (NAEI) to model the concentrations of pollutants at the centroid of each 1 km grid square but then calibrates these concentrations in relation to actual monitoring data.

The estimated annual mean background concentration of SO_2 from the PCM model for the 1km grid square covering the installation is 2.8 $\mu g\ m^{-3}$.

2.8.3 Local Air Quality Management

Torfaen County Borough Council (CBC), under its Local Air Quality Management (LAQM) obligations, continually reviews and assesses concentrations of key air pollutants in the borough to ascertain the requirement, or otherwise, to declare an Air Quality Management Area (AQMA).

Following the Review and Assessment studies to date, and confirmed in the recent 2011 Progress Report, Torfaen CBC has not declared any AQMAs within its jurisdictional area.

2.8.4 Background Concentrations used in the Assessment

Annual mean background concentrations have been derived from the Defra maps for the grid square centred on the installation. The annual average process contribution is added to the annual average background concentration to give a total concentration at each receptor location.

It is not technically rigorous to add predicted short-term or percentile concentrations to ambient background concentrations not measured over the same averaging period, since peak contributions from different sources would not necessarily coincide in time or location. Without hourly ambient background monitoring data available it is difficult to make an assessment

against the achievement or otherwise of the short-term AQS/AQO. For the current assessment, conservative short-term ambient levels have been derived by applying a factor of two to the annual mean background data as per the recommendation in Environment Agency Horizontal Guidance H1 Annex (f).

2.9 Sensitivity Analysis and Uncertainty

2.9.1 Sensitivity Analysis

Wherever possible, this assessment has used worst-case scenarios, which will exaggerate the impact of the emissions on the surrounding area, including emissions, operational profile, ambient concentrations, meteorology and surface roughness. This assessment has considered the years predicting the highest process contribution at the nearest receptor for comparison with the AQS/AQO.

Due to the known influence of local topographic effects on atmospheric flow, the assessment has undertaken additional sensitivity analysis using limited on-site wind speed and direction data.

2.9.2 Model Uncertainty

Dispersion modelling is inherently uncertain, but is nonetheless a useful tool in plume footprint visualisation and prediction of ground level concentrations. The use of dispersion models has been widely used in the UK for both regulatory and compliance purposes for a number of years and is an accepted approach for this type of assessment.

This assessment has incorporated a number of worst-case assumptions, as described above, which will result in an overestimation of the predicted ground level concentrations from the process. Therefore, the actual predicted ground level concentrations would be expected to be lower than this and, in some cases, significantly lower.

The model is well validated with observed concentrations for a number of scenarios; however, as the complexity of the modelled domain increases, modelled concentrations deviate from observed concentrations.

3. Assessment Criteria

3.1 Relevant Legislation and Guidance

3.1.1 EU Legislation

Directive 2008/50/EC on Ambient Air Quality and Cleaner Air for Europe
Directive 2008/50/EC (the 'Directive'), which came into force in June 2008, consolidates existing EU-wide air quality legislation (with the exception of Directive 2004/107/EC) and provides a new regulatory framework for $PM_{2.5}$.

The Directive sets limits, or target levels, for selected pollutants that are to be achieved by specific dates and details procedures EU Member States should take in assessing ambient air quality. The limit and target levels relate to concentrations in ambient air. At Article 2(1), the Directive defines ambient air as:

> *"…outdoor air in the troposphere, excluding workplaces as defined by Directive 89/654/EEC where provisions concerning health and safety at work apply and to which members of the public do not have regular access."*

In accordance with Article 2(1), Annex III, Part A, paragraph 2 details locations where compliance with the limit values does not need to be assessed:

> *"Compliance with the limit values directed at the protection of human health shall not be assessed at the following locations:*
>
> *a) any locations situated within areas where members of the public do not have access and there is no fixed habitation;*
>
> *b) in accordance with Article 2(1), on factory premises or at industrial installations to which all relevant provisions concerning health and safety at work apply;*
>
> *c) on the carriageway of roads; and on the central reservation of roads except where there is normally pedestrian access to the central reservation.*

3.1.2 UK Legislation

The Air Quality Standards Regulations 2010
The Air Quality Standards Regulations 2010 (the 'Regulations') came into force on the 11th June 2010 and transpose Directive 2008/50/EC into UK legislation. The Directive's limit values are transposed into the Regulations as 'Air Quality Standards' (AQS) with attainment dates in line with the Directive.

These standards are legally binding concentrations of pollutants in the atmosphere which can broadly be taken to achieve a certain level of environmental quality. The standards are based on

the assessment of the effects of each pollutant on human health including the effects of sensitive groups or on ecosystems.

Similar to Directive 2008/50/EC, the Regulations define ambient air as;

> *"…outdoor air in the troposphere, excluding workplaces where members of the public do not have regular access."*

with direction provided in Schedule 1, Part 1, Paragraph 2 as to where compliance with the AQS' does not need to be assessed:

> *"Compliance with the limit values directed at the protection of human health does not need to be assessed at the following locations:*
>
> *a) any location situated within areas where members of the public do not have access and there is no fixed habitation;*
>
> *b) on factory premises or at industrial locations to which all relevant provisions concerning health and safety at work apply;*
>
> *c) on the carriageway of roads and on the central reservation of roads except where there is normally pedestrian access to the central reservation."*

The Air Quality Strategy for England, Scotland, Wales and Northern Ireland

The 2007 Air Quality Strategy for England, Scotland Wales and Northern Ireland provides a framework for improving air quality at a national and local level and supersedes the previous strategy published in 2000.

Central to the Air Quality Strategy are health-based criteria for certain air pollutants; these criteria are based on medical and scientific reports on how and at what concentration each pollutant affects human health. The objectives derived from these criteria are policy targets often expressed as a maximum ambient concentration not to be exceeded, without exception or with a permitted number of exceedences, within a specified timescale. At paragraph 22 of the 2007 Air Quality Strategy, the point is made that the objectives are:

> *"…a statement of policy intentions or policy targets. As such, there is no legal requirement to meet these objectives except where they mirror any equivalent legally binding limit values…"*

The air quality objectives (AQOs), based on a selection of the objectives in the Air Quality Strategy, were incorporated into UK legislation through the Air Quality Regulations 2000, as amended.

Paragraph 4(2) of The Air Quality (England) Regulations 2000 states:

> *"The achievement or likely achievement of an air quality objective prescribed by paragraph (1) shall be determined by reference to the quality of air at locations –*
>
> *(a) which are situated outside of buildings or other natural or man-made structures above or below ground; and*
>
> *(b) where members of the public are regularly present*

Consequently, compliance with the AQOs should focus on areas where members of the general public are present over the entire duration of the concentration averaging period specific to the relevant objective.

3.1.3 Local Air Quality Management

Part IV of the Environment Act 1995 requires that Local Authorities periodically review air quality within their individual areas. This process of Local Air Quality Management (LAQM) is an integral part of delivering the Government's AQOs.

To carry out an air quality Review and Assessment under the LAQM process, the Government recommends a three-stage approach. This phased review process uses initial simple screening methods and progresses through to more detailed assessment methods of modelling and monitoring in areas identified to be at potential risk of exceeding the objectives in the Regulations.

Review and assessments of local air quality aim to identify areas where national policies to reduce vehicle and industrial emissions are unlikely to result in air quality meeting the Government's air quality objectives by the required dates.

For the purposes of determining the focus of Review and Assessment, Local Authorities should have regard to those locations where members of the public are likely to be regularly present and are likely to be exposed over the averaging period of the objective.

Where the assessment indicates that some or all of the objectives may be potentially exceeded, the Local Authority has a duty to declare an AQMA. The declaration of an AQMA requires the Local Authority to implement an Air Quality Action Plan (AQAP), to reduce air pollution concentrations so that the required AQOs are met.

3.1.4 Other Guideline Values

In the absence of statutory standards for the other prescribed substances that may be found in the emissions, there are several sources of applicable air quality guidelines.

Air Quality Guidelines for Europe, the World Health Organisation (WHO)

The aim of the WHO Air Quality Guidelines for Europe (WHO, 2000) is to provide a basis for protecting public health from adverse effects of air pollutants and to eliminate or reduce exposure to those pollutants that are known or likely to be hazardous to human health or well-being. These guidelines are intended to provide guidance and information to international, national and local authorities making risk management decisions, particularly in setting air quality standards.

Environmental Assessment Levels (EALs)

The Environment Agency's Horizontal Guidance Note H1 provides methods for quantifying the environmental impacts of emissions to all media. H1 Annex (f) contains long and short-term Environmental Assessment Levels (EALs) and Environmental Quality Standards (EQS) for releases to air derived from a number of published UK and international sources. For the pollutants considered in this study, these EALs and EQS are equivalent to the AQS and AQOs set in force by the Air Quality Strategy for England, Scotland Wales and Northern Ireland.

H1 Annex (f) provides a three-tiered approach to assessing the significance of emissions to atmosphere. The first stage is to 'screen out' insignificant emissions to air; these are emissions which are emitted in such small quantities that they are unlikely to cause a significant impact on the receiving environment. This procedure is detailed in Box 1.

Box 1 Screening out Insignificant Emissions to Air

Identify which emissions can be excluded from further assessment by applying the criteria below:

- **Long-term Process Contribution (PC) < 1% of the relevant long-term EAL**
- **Short-term PC < 10% of the relevant short-term EAL**

Those releases which **satisfy the above criteria** can be classed as **insignificant** and excluded from further assessment. Those releases which **do not satisfy the above criteria** can be classed as **not insignificant** and warrant further assessment.

The second stage is to assess the need for detailed dispersion modelling of emissions to air (Box 2). If the second stage indicates that further investigation is warranted, a detailed assessment of emissions to air should be undertaken using an appropriate dispersion model, such as ADMS or AERMOD (the third stage assessment). It should be noted that once a decision has been made to proceed to detailed modelling, the insignificance criteria described in Box 1 are no longer relevant and shouldn't be used in the assessment of impact. Rather, the impact assessment should focus only on achievement with the appropriate EAL.

Box 2 Identifying the Need for Detailed Modelling of Emissions to Air

For those releases which cannot be screened by the criteria detailed in Box 1, the following approach should be used in identifying whether detailed modelling of emissions to air is required.

Long Term Impacts

1. Obtain information on the annual mean background concentrations (BG) of releases to air
2. Calculate the Predicted Environmental Concentration (PEC) of that substance by summing the PC and BG, i.e., **PEC = PC + BG**
3. Detailed dispersion modelling **is required** if **PEC > 70% of the EAL**

Short Term Impacts

1. Calculate the difference between the long-term background concentration and short-term EAL (model headroom)
2. Detailed dispersion modelling **is required** if the **short-term PC > 20% of model headroom**
3. Short-term Process Contributions not exceeding 20% of the short-term EAL "may be considered to be tolerable".

3.2 Air Quality Impacts of the Process

The atmospheric emissions of SO_2 have been identified as requiring detailed dispersion modelling. A brief description of the principal sources and effects of SO_2 in the environment is provided in Table 3.1.

Table 3.1 Summary of the Pollutants Assessed

Pollutant	Description and effect on human health and the environment	Principal Sources
Sulphur Dioxide (SO_2) [A]	At high concentrations SO_2 is a potent bronchoconstrictor, and asthmatic individuals are more susceptible. It is likely that SO_2 contributes to respiratory symptoms, reduced lung function and rises in hospital admissions. Exposure to high levels of SO_2 over a long period can result in structural changes in the lungs and may enhance sensitisation to allergens.	The principal source of SO_2 is the combustion of fossil fuels containing sulphur and, in the UK, this is primarily through the combustion of coal in power stations, oil refining and solid fuel manufacturing, accounting for 57% of total UK SO_2 emissions in 2008.

B Harrison, R.M., *Air Pollution: Sources, Concentrations and Measurements*. In: Harrison, R.M., 2000, *Pollution: Causes, Effects and Controls*, 4th Edition Royal Society of Chemistry.

3.3 Criteria Appropriate to the Assessment

Table 3.2 sets out those AQS and AQOs that are relevant to this assessment.

Table 3.2 Air Quality Standards and Objectives

Pollutant	AQS/AQO	Averaging Period	Value ($\mu g\ m^{-3}$)
Sulphur dioxide (NO_2)	AQO	15-min mean, not to be exceeded more than 35 times a year (equivalent to 99.9 percentile)	266
	AQS	1-hour mean not to be exceeded more than 24 times a year (equivalent to 99.73 percentile)	350
	AQS	24-hour mean, not to be exceeded more than 3 times a year (equivalent to 99.18 percentile)	125
	AQS	Annual mean for the protection of ecosystems	20

4. Assessment of Impact

This section sets out the results of the inverse modelling and provides predicted concentrations of SO_2 from the furnace stack that would contribute to incremental percentage contributions of the relevant AQS/AQO.

4.1 Meteorological Data Sensitivity Analysis

Results are presented in the subsequent section for the meteorological year resulting in the highest process contribution at the specific receptor experiencing the maximum impact from the installation. The worst-case was determined separately for long- and short-term concentrations at the worst-case human receptor (15-minute mean, 1-hour mean and 24-hour mean metrics) and ecological receptor (annual mean metric only) location by setting a unitary emission rate of 1 g s^{-1} from the furnace stack. Due to the use of a unit emission rate, these results are, by definition, equivalent to dispersion factors (µg m^{-3} g^{-1} s^{-1}) The results are presented in Table 4.1 for Rhoose meteorological data.

Table 4.1 Determination of Worst-case Dispersion Factors (Rhoose 2006-2010 Data)

Year	Predicted Ground Level Concentration per Unit Emission of SO_2 (µg m^{-3} g^{-1} s^{-1})			
	Annual Mean	**99.9%-ile 15-minute Mean**	**99.73%-ile 1-hour Mean**	**99.18%-ile 24-hour Mean**
2006	**0.0096**	3.76	3.16	1.46
2007	0.0091	**3.81**	3.24	1.81
2008	0.0088	3.69	3.22	1.79
2009	0.0098	3.64	3.14	1.87
2010	0.0081	3.60	**3.28**	**1.98**

As discussed in section 2.3, it is known that, due to local terrain influences, the prevailing wind direction in the local area is southerly, whereas data from Rhoose indicates a prevailing westerly wind. Additional sensitivity analysis has been undertaken by comparing maximum values obtained using 2006-2010 data from Rhoose and 2009-2010 data from the on-site instrumentation; these being the years where a complete annual data set is available from the on-site station. The results are presented in Table 4.2.

Table 4.2 Rhoose and On-site Meteorological Data Sensitivity Analysis

Station	Predicted Ground Level Concentration per Unit Emission of SO_2 (µg m^{-3} g^{-1} s^{-1})			
	Annual Mean	**99.9%-ile 15-minute Mean**	**99.73%-ile 1-hour Mean**	**99.18%-ile 24-hour Mean**
Rhoose (max)	**0.0096**	3.81	3.28	1.98
On-site (2009 data)	0.0050	**4.57**	4.00	**2.00**
On-site (2010 data)	0.0044	4.56	**4.17**	1.83

Notes:

The on-site station does not record temperature or cloud cover and, consequently, these parameters have been substituted with Rhoose data.

As a conservative approach, for the results presented in the following section, the inverse modelling has been undertaken based on the values highlighted in bold in Table 4.2 for each individual AQS/AQO averaging period.

4.2 Model Results

Figure 4.1 plots the incremental percentage contribution of process emissions towards the respective SO_2 AQS/AQO as a function of stack concentration, based on the methodology described in Section 2 and using the dispersion factors derived above in Table 4.2. As the derived annual mean dispersion is several orders of magnitude lower than the short-term AQS/AQOs, annual mean results have not been plotted but are available in tabular form in Appendix A.

The figure reveals that stack concentrations in the order of 7,800 mg Nm^{-3} would be required before any of the AQS/AQOs would be breached. For process contributions to no longer be defined as 'insignificant' under the guidance in H1 Annex f, emission concentrations in the order of 750 mg Nm^{-3} would be required.

Based on the inverse modelling data, algorithms for estimating the percentage contribution of SO_2 emissions towards the AQS/AQO at the worst-case receptor ($C_a(\%)$) as a function of stack concentration (C_s) can be derived. The algorithm takes the form:

$$C_a(\%) = f(C_s) \quad (3)$$

Where:

$f(C_s) = 0.012C_s$; for 15-minute mean predictions

$f(C_s) = 0.011C_s$; for 24-hour mean predictions

$f(C_s) = 0.008C_s$; for 1-hour mean predictions

$f(C_s) = 3.6 \times 10^{-4} C_s$; for annual mean predictions

Alternatively, the inverse algorithm of (3) can be used to estimate the stack concentration for a particular percentage contribution of SO_2 emissions towards the AQS/AQO at the worst-case receptor:

$$C_s = f(C_a(\%)) \quad (4)$$

Where:

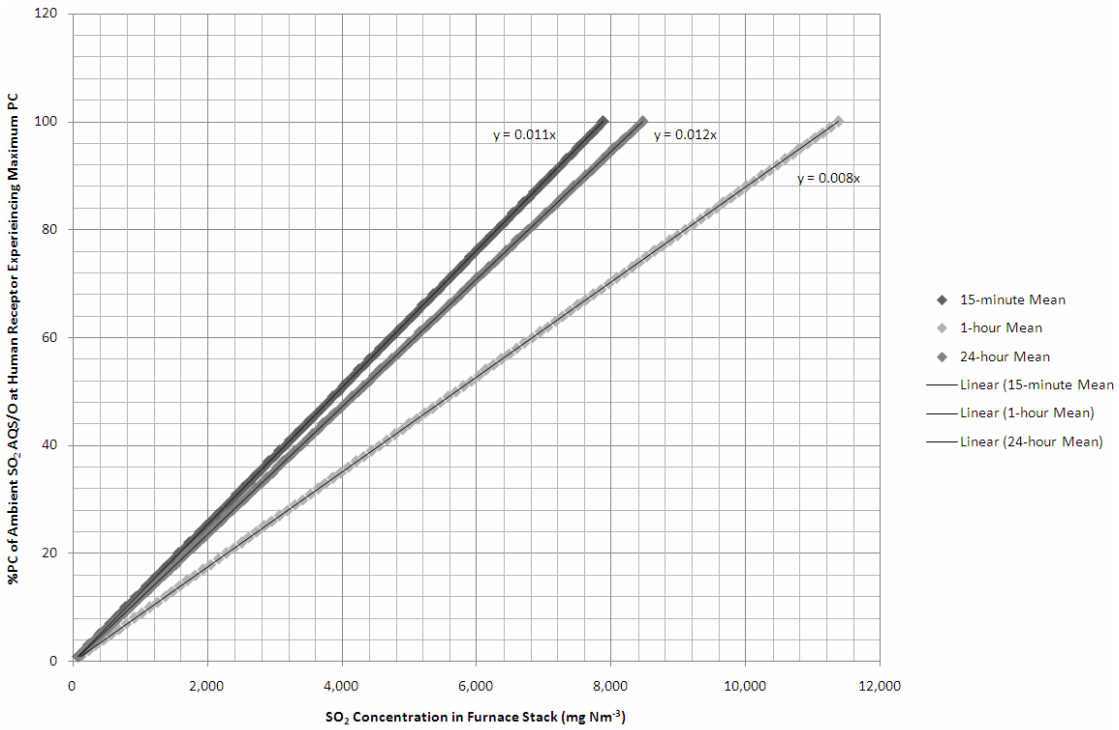
$f(C_a(\%)) = 83.3C_a(\%)$; for 15-minute mean predictions

$f(C_a(\%)) = 90.9C_a(\%)$; for 24-hour mean predictions

$f(C_a(\%)) = 125C_a(\%)$; for 1-hour mean predictions

$f(C_a(\%)) = 2777C_a(\%)$; for annual mean predictions

Figure 4.1 Results of Inverse Modelling of Furnace Stack SO_2 Emissions



5. Conclusions

This assessment has utilised inverse modelling techniques based on detailed dispersion modelling to establish relationships between the SO_2 emission concentration from the furnace stack and the percentage contribution of process emissions towards the ambient SO_2 AQS/AQOs.

Data from recent stack emission monitoring surveys, and five years of meteorological data from Rhoose, supplemented with two years of wind speed and direction data recorded by the on-site weather station, have been used to derive dispersion factors for each of the respective SO_2 AQS/AQOs.

Based on these factors, the assessment predicts that stack emissions concentrations in the order of 7,800 mg Nm^{-3} would be required before any of the AQS/AQOs would be breached at any of the receptors identified in this assessment. For process contributions to no longer be defined as 'insignificant' under the guidance in H1 Annex f, emission concentrations in the order of 750 mg Nm^{-3} would be required at any of the receptors identified in this assessment. At this concentration, and allowing for the ambient background concentration of 2.8 µg m^{-3} and typical model uncertainty of 50% with respect to shorter-term predictions, predicted environmental concentrations would still be well below the AQS/AQO at the worst-case receptor.

It should, however, be noted that the dispersion factors and algorithms derived in this assessment are an intrinsic function of stack process parameters, including efflux velocity and efflux temperature. If these parameters were to change significantly, the conclusions of this assessment would no longer be valid.

6. References

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Appendix A
Inverse Modelling Tabular Data

4 Pages

Table A.1 Inverse Modelling Tabular Output

Percentage of AQS/AQO	Equivalent Stack Concentration (mg Nm^{-3}) Required to Achieve the Percentage of the AQS/AQO Value			
	Annual Mean	99.9%-ile 15-minute Mean	99.73%-ile 1-hour Mean	99.18%-ile 24-hour Mean
1	2766	79	114	85
2	5532	158	228	169
3	8298	237	341	254
4	11064	315	455	339
5	13830	394	569	423
6	16596	473	683	508
7	19362	552	796	593
8	22128	631	910	677
9	24894	710	1024	762
10	27660	788	1138	847
11	30426	867	1251	931
12	33192	946	1365	1016
13	35958	1025	1479	1100
14	38724	1104	1593	1185
15	41490	1183	1706	1270
16	44256	1261	1820	1354
17	47022	1340	1934	1439
18	49788	1419	2048	1524
19	52554	1498	2161	1608
20	55320	1577	2275	1693
21	58086	1656	2389	1778
22	60851	1734	2503	1862
23	63617	1813	2616	1947
24	66383	1892	2730	2032

Table A.1 (continued) Inverse Modelling Tabular Output

Percentage of AQS/AQO	Equivalent Stack Concentration (mg Nm^{-3}) Required to Achieve the Percentage of the AQS/AQO Value			
	Annual Mean	99.9%-ile 15-minute Mean	99.73%-ile 1-hour Mean	99.18%-ile 24-hour Mean
25	69149	1971	2844	2116
26	71915	2050	2958	2201
27	74681	2129	3071	2286
28	77447	2207	3185	2370
29	80213	2286	3299	2455
30	82979	2365	3413	2540
31	85745	2444	3526	2624
32	88511	2523	3640	2709
33	91277	2602	3754	2793
34	94043	2680	3868	2878
35	96809	2759	3981	2963
36	99575	2838	4095	3047
37	102341	2917	4209	3132
38	105107	2996	4323	3217
39	107873	3075	4436	3301
40	110639	3153	4550	3386
41	113405	3232	4664	3471
42	116171	3311	4778	3555
43	118937	3390	4891	3640
44	121703	3469	5005	3725
45	124469	3548	5119	3809
46	127235	3626	5233	3894
47	130001	3705	5346	3979
48	132767	3784	5460	4063
49	135533	3863	5574	4148
50	138299	3942	5688	4233
51	141065	4021	5802	4317
52	143831	4099	5915	4402
53	146597	4178	6029	4486
54	149363	4257	6143	4571
55	152129	4336	6257	4656

Table A.1 (continued) Inverse Modelling Tabular Output

Percentage of AQS/AQO	Equivalent Stack Concentration (mg Nm^{-3}) Required to Achieve the Percentage of the AQS/AQO Value			
	Annual Mean	99.9%-ile 15-minute Mean	99.73%-ile 1-hour Mean	99.18%-ile 24-hour Mean
56	154895	4415	6370	4740
57	157661	4494	6484	4825
58	160427	4572	6598	4910
59	163193	4651	6712	4994
60	165959	4730	6825	5079
61	168725	4809	6939	5164
62	171491	4888	7053	5248
63	174257	4967	7167	5333
64	177022	5045	7280	5418
65	179788	5124	7394	5502
66	182554	5203	7508	5587
67	185320	5282	7622	5672
68	188086	5361	7735	5756
69	190852	5440	7849	5841
70	193618	5518	7963	5926
71	196384	5597	8077	6010
72	199150	5676	8190	6095
73	201916	5755	8304	6179
74	204682	5834	8418	6264
75	207448	5913	8532	6349
76	210214	5991	8645	6433
77	212980	6070	8759	6518
78	215746	6149	8873	6603
79	218512	6228	8987	6687
80	221278	6307	9100	6772
81	224044	6386	9214	6857
82	226810	6464	9328	6941
83	229576	6543	9442	7026
84	232342	6622	9555	7111
85	235108	6701	9669	7195
86	237874	6780	9783	7280

Table A.1 (continued) Inverse Modelling Tabular Output

Percentage of AQS/AQO	Equivalent Stack Concentration (mg Nm^{-3}) Required to Achieve the Percentage of the AQS/AQO Value			
	Annual Mean	99.9%-ile 15-minute Mean	99.73%-ile 1-hour Mean	99.18%-ile 24-hour Mean
87	240640	6859	9897	7365
88	243406	6937	10010	7449
89	246172	7016	10124	7534
90	248938	7095	10238	7619
91	251704	7174	10352	7703
92	254470	7253	10465	7788
93	257236	7332	10579	7872
94	260002	7410	10693	7957
95	262768	7489	10807	8042
96	265534	7568	10920	8126
97	268300	7647	11034	8211
98	271066	7726	11148	8296
99	273832	7805	11262	8380
100	276598	7883	11375	8465