THE CLIMATIC AIR CLEANING TECHNOLOGY FOR WIND TURBINE BLADE MANUFACTURING

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INFUSER APS is a cleantech company located in Copenhagen, Denmark focused on developing air cleaning products based on **GAS PHASE ADVANCED OXIDATION.** Using a **SEQUENTIAL TREATMENT APPROACH** by combining of **UV LIGHT, OZONE AND OTHER GASEOUS OXIDANTS**, the technology can **REMOVE VOLATILE ORGANIC COMPOUNDS FROM INDUSTRIAL VENTILATION AND PROCESS AIR.** For example, for emissions related to production of **WIND TURBINE BLADES**, the technology is **VASTLY SUPERIOR TO CONVENTIONAL TECHNOLOGIES**, such as activated carbon and combustion in terms of cost and waste. This whitepaper explains the air pollution problems commonly associated with wind turbine blade manufacturing and how the **CLIMATIC** technology has solved these.

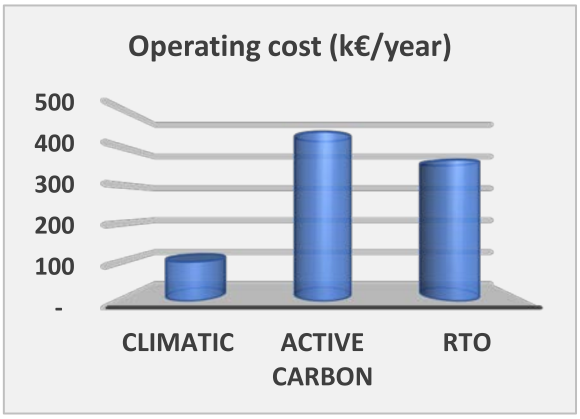

Figure 1: Examples of operating cost of a single emission point on a wind turbine blade production line of 50,000 m3/h (see section 6 for further information).

Figure2: CLIMATIC installation for 50,000 m3/h (2017).

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1. Introduction to wind power development

The availability of cheap and reliable energy has always been one of the most important prerequisites for economic development. In fact, it is well known that energy consumption and living standard are strongly correlated [1] and that energy use will continue to increase in the foreseeable future.[2] For more than a century, the backbone of global energy supply has been fossil fuels, but due to concerns about global warming and energy security, renewable energy sources, such as wind power, are now increasingly being preferred.

Since the early development of efficient wind turbines in the 1980's, wind energy has been one of the most rapidly expanding energy sources, with yearly growth rates between 20 and 25% [3] The increasing efficiency of wind turbines has, amongst other factors, been driven by the capability to produce increasingly large wind turbine blades. At present, the largest blades in production are between 80 and 90 meters, but blades exceeding 100 meters are being developed. [4] As can be expected, production and transportation of such large items has led to challenges that requires new and innovative products.

2. Emission problems in manufacturing

While wind energy is providing clean energy during operation, the manufacturing of the turbines and turbine blades emit VOCs. Not only is this causing non-acceptable working conditions for the workers and other personnel in the manufacturing process but leading to damaging gasses and particles emitted into the atmosphere.

Modern blades are largely made from fiber reinforced plastic and the most commonly used plastics are styrene- or epoxy-based. Due to the specific requirements of the production, the plastic polymers are synthesized onsite from the raw materials, i.e. resins and binders.

The handling and application of large quantities of such chemicals is a safety concern in itself, but further, due to the volatility of the chemicals and the large surface area of the mold, considerable evaporation is inevitable. Immediately, this leads to an air quality problem within the factory hall, which can be solved in two ways:

1. Personal protection equipment worn by workers
   Although this is a known method, the safety equipment, e.g. facemask and air filter, is a significant hassle and will lower the productivity of the factory. Hence, this method is not suitable for intensive production facilities.
2. Increase of ventilation rate
   This method removes the polluted air and replaces this with fresh outdoor air. Due to the increasing size of wind-turbine blades and the factory halls, even moderate ventilation rates, e.g. 5 per hour, leads to air volumes of more than 500,000 m3/h for a single factory hall. Further, the emission of the VOC to the atmosphere may be restricted by law and the associated air cleaning equipment has until now been both very large, as well as expensive to buy and operate (See Figure 1).

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2.1 Styrene and polystyrene

Polystyrene is produced from styrene, which is a liquid hydrocarbon with a characteristic sweet odor. Millions of tons of styrene are produced annually, mainly from crude oil and mainly intended for polymerization.[5]

The vapor pressure of styrene is more than 6,000 ppm at room temperature, so production of polystyrene is most often accompanied by styrene evaporation and hence, exposure to the workers. Further, since styrene is classified as a possible carcinogen and as a toxin, the commonly employed 8 hour exposure limit is just 10 ppm. Consequently, comparatively high air exchange rates of 3-5 times per hour must be employed to avoid excessive use of personal protection equipment.

2.2 Epoxy

Epoxy based plastics are synthesized from an epoxide (a three atom cyclic ether) and a hardener, e.g. an isocyanate, polyamine or a phenolic compound. A wide variety of epoxides and hardeners may be used, leading to polymers with vastly different properties. Common examples include bisphenol-based epoxides and phenylbased diisocyanates or triethylene-tetraamine hardeners.

Although these compounds have quite low vapor pressures, the polymerization often entails undesirable side-reactions, inducing production of more volatile compounds, and consequently an air pollution problem. Further, many epoxides and hardeners are known carcinogens and irritants and high ventilation rates are therefore employed.

3. Science and technology

Figure 3: CLIMATIC installation for max. 25,000 m3/h (2017).

Figure 4: Two UVR-WAC installations for a combined flow of 85,000 m3/h (2017).

Air pollution can be divided into three categories:

1. Inorganic pollutants, mainly SO_2, NO_x and CO
2. Particulate matter, mainly soot and mineral dust

   Both are mainly related to combustion of any kind of carbon, hydrocarbon or biomass.[6] The third class of air pollutants is very broad, and has numerous origins:

3. Organic pollutants, mainly volatile organic compounds (VOC)

These refer to compounds which normally are liquid at room temperature, normally containing from 1 to 10 carbon atoms and a number of functional groups such as acids, aldehydes, ketones, and rings.[7]

These are encountered at a wide variety of industrial processes, either as reactants, intended products or as by-products. Regardless of which, they will to larger or smaller extend evaporate when exposed to open air, leading to pollution of the air and the environment.

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4. Wind power solution

In close collaboration with the University of Copenhagen, INFUSER ApS has developed and implemented the patented CLIMATIC air purification technology for gas phase treatment of industrial air pollution.[8] The technology is based on accelerating the self-cleansing mechanisms of the atmosphere, namely a carefully adjusted combination of gaseous oxidants, water vapor and UV light.[9] This produces OH radical molecules (Reaction 1) which are extremely reactive towards most VOCs (Reaction 2).

O_3 + UV light	→	OH	(Reaction 1)
VOC + OH	→	OxVOC	(Reaction 2)

The VOCs are thereby first oxidized to OxVOCs, but thereafter precipitate out of the gas phase as particles (Reaction 3).

OxVOC	→	Particle	(Reaction 3)

This leaves the gas with a reduced amount of VOCs, but with elevated concentrations of aerosol particles and ozone, and possibly semi-oxidized VOCs. Such a mixture should not be emitted to the atmosphere and a second treatment stage is therefore required. Many designs are possible, but a multibed ozone removal catalyst with VOC adsorption capabilities has proven to be the most economical and practical. By choosing the correct catalyst medium, the ozone removal is accompanied by conversion of semi-oxidized VOCs to OxVOCs as

Semi OxVOC + O3	→	OxVOC	(Reaction 4).

Further, the filter is designed to capture the produced aerosol particles so a compact and efficient design is then realized.

Such a filter can either be exchanged at suitable intervals, but in industrial applications, it is often more practical to install an automated washing of the filter medium. Although this produces some wastewater, the high solubility of the OxVOCs (often more than 10,000 times higher than the original VOC), the amount of wastewater is minimal, and this can often be discarded with little or no extra treatment.

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5. Real-life data

A CLIMATIC installation is by default equipped with an array of sensors, enabling the operator to follow the efficiency either locally at the machine or the factory, or remotely via the modem and SCADA system. Further, all data is logged which can be used in reporting and error prediction.

As an example, 24 hours of operating data of a CLIMATIC installation is shown in Figure 5 (a summary of 42 consecutive days in 2017 is shown in Table 1). In the top section, the overall removal efficiency is seen to be between 80 and 90% and the emissions is seen to be very low at any given time.

In the middle section, the actual measurement values of the permanently installed sensors are shown. At one point, probably at the beginning of a molding cycle, the inlet sensor is seen to saturate, i.e. the pollution is above the maximum value. Nonetheless, the emission is seen to be low, even during this very high load.

At the bottom section, the air flow and the total pressure drop of the system is illustrated. Notice that conventional cleaning technologies have pressure drops about 10-50 times higher than a CLIMATIC installation, in this case translating to some 20 to 100 kW of saved energy for fan power alone.

Further sensors include an array of thermal sensors, water level sensors, energy sensors and safety sensors.

Table 1: Summary of the styrene removal efficiencies over 42 consecutive days in 2017.

CLIMATIC UVR-WAC	Unit	Inlet	Outlet	Reduction
Average styrene conc.	mg/m3	4.71	0.59	87%
Average styrene flow	kg/h	0.228	0.028	87%
Accumulated styrene flow	kg	38.3	4.86	87%

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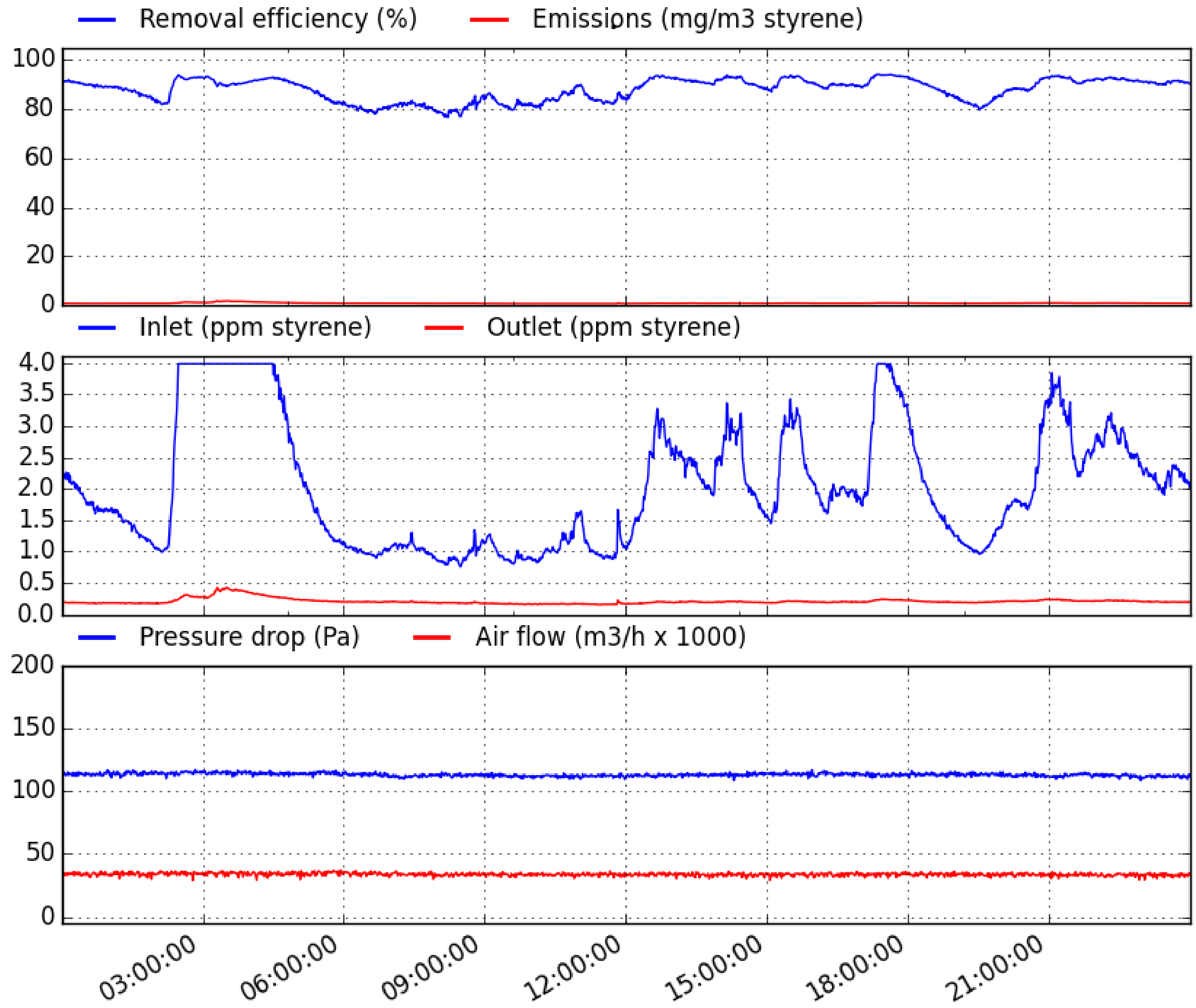

Figure 5: Summary of data from a CLIMATIC installation during one day of normal production of a major European blade OEM. As can be seen, the emissions are constantly very low, and the removal rates are very high.

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6. Cost comparison

When considering a system for air pollution control for an industrial production facility, such as a wind turbine blade manufacturing, it can be tempting to focus on the purchasing price. However, it is not uncommon that the annual OPEX accounts for more than 50% of the initial CAPEX, and hence OPEX is the key factor to focus on, when determining the lifetime cost. INFUSER uses "CLIMATIC Total Cost of Ownership" model, when designing a product, taking into account all costs over the lifetime of the product and/or the depreciation period.

The conventional technologies for emission profiles such as those from blade manufacturing are adsorption by activated carbon and combustion by a recuperative thermal oxidizer (RTO). The cost drivers for these technologies are listed in Table 2, along with the cost drivers for the CLIMATIC technology.

CLIMATIC	Activated carbon	RTO
Electricity for UV lamps	Replacement of activated carbon	Natural gas
Replacement UV lamps	Electricity for fan	Electricity for fan

Table 2: Overview of the primary cost drivers for the CLIAMTIC technology and the conventional technologies (see also Figure 1).

For the CLIMATIC technology, the primary cost drivers relate to the UV lamps. Infuser uses European built UV lamps of highest quality only. This keeps the electricity cost low, since fewer lamps are needed to clean a given emission, in comparison using lower quality lamps. Further, the lamps are built using the "long-lift coating" concept which maximizes the useful lifetime.

For the activated carbon technology, the primary cost driver is the replacement of the spent activated carbon medium. Due to the comparatively low concentrations encountered in wind turbine blade manufacturing, the adsorption capacity of the activated carbon is drastically reduced, often to below 5% by weigth. This increases the carbon use dramatically, compared to other applications where adsorption capacities of 20-30% can be realized. Further, due to the very large air flows, the pressure drop can be very high, often between 3,000 and 5,000 Pa, imposing high demand on fan capacity and electricity use.

For the RTO technology, the dominant cost driver is the natural gas, which must be added to maintain a suitable temperature in the burning chamber of some 800 to 850°C. In other applications, with higher pollution concentrations, a significant amount of the natural gas can be saved since the pollution itself adds energy to the process. However, for wind turbine blade manufacturing, the concentrations are so low that this contribution is negligible. Further, a substantial pressure drop of 3,000 to 4,000 Pa is normal, again posing high demands on fan and fan power.

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7. Conclusion

By using UV light and advanced oxidation, the CLIMATIC technology by Infuser ApS has in recent years evolved into a competitive product for air pollution control at wind turbine blade production facilities. The technology has proven to be reliable and efficient and with highly attractive operating expenses and total cost of ownership compared to conventional technologies.

The CLIMATIC installation removes both the primary pollution, such as styrene, epoxy or isocyanates, but also any secondary pollution, including ozone, aerosol particles and semi oxidized VOCs. Using specially designed filter and filter medium with automated cleaning capabilities, the service and maintenance is kept at a minimum. Further, the customized SCADA system is designed to generate automated pollution reports based on the installed sensors for example for use in official documentation of emission compliance.

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