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Newly developed facilities for off-gas cleaning

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Due to industrial demand novel types of equipment for cleaning off-gas and flue gas generated in various branches of the industry were developed as follows:

- Equipment for thermal and catalytic treatment of waste gases polluted by VOC and carbon monoxide (alternatively NO_X)
- Equipment for wet cleaning of flue gases polluted by SO_2, HCl and HF with a novel type of homogenizer "O-element"
- Combined experimental equipment for cleaning of waste gases polluted by solid particulates, SO_2, HCl, HF and heavy metals (alternatively NO_X or PCDD/F)

The outstanding features of all equipment mentioned above are low investment and operating costs together with high removing efficiency of pollutants. These units can be used mainly in incineration plants, refineries and other chemical plants.

Keywords: waste gas, off-gas, flue gas, air pollutants, emission reduction

1. Introduction

Chemical industry generate off-gases and flue gases containing a large number of contaminants such as: VOC (Volatile organic compounds), CO, NOx, SO_2, HCl, HF, solid particles and PCDD/F (Dioxins). The strict legislative requirements force to remove these compounds by means of up to date technologies characterized by low investment and operating cost simultaneously with their effective removal. Therefore, three new units were developed for reducing undesirable compounds present in off-gases and flue gases with high efficiency. The present-day techniques (e.g. modelling of flow using CFD (Computational Fluid Dynamics)) together with experience obtained during cooperation with the industry were applied during their development.

2. Novel types of equipment

2.1 Equipment for thermal and catalytic treatment of waste gases polluted by VOC and carbon monoxide (alternatively NO_X)

The equipment shown in Figure 1 has been designed to remove VOC, carbon monoxide and NO_X (Stulir R. (2001), Dvorak R. (2007)). It should be used especially for treatment of small flow rates of off-gas with a large concentration of the already mentioned pollutants. For removing VOC and carbon monoxide thermal oxidation process with temperatures in the combustion chamber higher than 600°C or catalytic oxidation with temperatures between 150 do 350°C are used. For catalytic oxidation catalysts Pt/Al_2O_3 or Pd/Al_2O_3 are used most frequently but others including Rh, CrO_3, CuO, Co_2O_3 or V_2O_5 distributed as layers on Al_2O_3, SiO_2, TiO_2 carriers or zeolites can also be used.

Within the processing of VOC with spatial velocity of 30,000 $m_N^3/(m^3.hr)$ it's possible to achieve approximately 99 % degree of conversion. When spatial velocity is 60,000 $m_N^3/(m^3.hr)$ the degree of conversion is around 90 %. For the removal of NO_X the process of selective catalytic reduction (SCR) is used i.e. at temperatures between 200 to 250°C flue gas passes through a catalyst bed (usually V_2O_5/TiO_2), where NO_X with NH_2-X compounds react (with X = H, CN or $CONH_2$). These compounds are injected into the flow of flue gas before the equipment.

This equipment helps to process off-gas with a concentration of pollutants from hundreds of mg/m_N^3 to units of g/m_N^3 (Stehlik P. (2004)). For the treatment at lower levels (tens of mg/m_N^3) and high flow rates (up to hundreds of thousands m_N^3/h) it is advised to combine this equipment with units for concentration of off-gases, i.e. adsorbtion systems or rotary concentrators.

The equipment consists of three main parts – cylindrical combustion chamber, catalytic reactor and coaxial heat exchanger, these parts are integrated into one equipment. Preheating of waste gas provides the special heat exchanger, which consists of several concentric cylindrical plates. Flue gas from the combustion chamber (catalytic reactor) and waste gas (which is heated by flue gas) spiral flow in the spaces between these plates. Thanks to this solution good effectivity of heat exchange is achieved. Thermal/catalytic oxidation of waste gas proceeds in cylindrical combustion chamber/catalytic reactor. The combustion chamber is placed inside the coaxial heat exchanger in its axial axis and the catalytic reactor is placed below the combustion chamber. Therefore the equipment is very compact – the combustion chamber, catalytic reactor and heat exchanger are concentrated in small volume. There are no pipelines needed for connection of combustion chamber, catalytic reactor and heat exchanger in this case. Next advantage of designed construction is low heat losses. It follows easier achieving of the auto-thermal regime (it is not necessary to supply next auxiliary fuel into the natural gas burner), namely at combustion of higher concentration of combustibles pollutants. Then the auxiliary fuel is used at starting/stopping equipment only or in time, when the concentration of combustibles pollutants in waste gas is low.

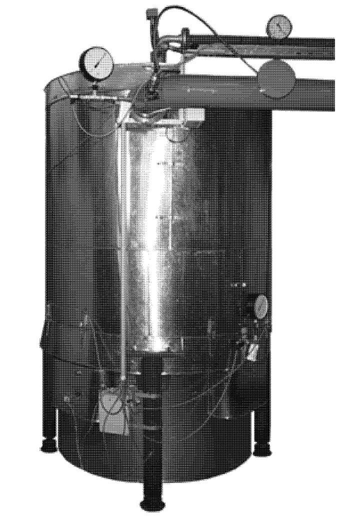

Figure 1 Compact equipment

Within the research an experimental unit was designed and built. This unit is used for abatement of volatile organic compounds, alternatively also for removing of carbon monoxide. Numerous experimental measurements have been carried out on this unit. Following operation parameters were monitored during the measurements: temperature and pressure at several points of unit, flow rate of natural gas, flow rate of off-gas and flue gases, concentration of various pollutants at the inlet and outlet. The alteration of composition of off-gas is achieved by injection of various liquid organic compounds into air.

2.2 Equipment for wet cleaning of flue gases polluted by SO_2, HCl and HF with novel type of homogenizer "O-element"

Equipment with novel design proposed for wet cleaning was developed as an alternative to wide-spread conventional device: Venturi scrubber. This new equipment represents a homogenizer "O-element" (Filip M. (2005)). Wet scrubbing of flue gases polluted by SO_2, HCl, HF and heavy metals is one of the cleaning methods used in the incineration plants of municipal waste and in the chemical industry as well.

Wet scrubbing takes advantages of absorption processes. Pollutants diffuse into appropriate liquid absorbent which is injected into the flow of flue gases. The alkali agent like lime or sodium hydroxide is in common use. In this case a chemical reaction occurs between absorbent and undesirable compounds which results to higher efficiency of absorption process (Talaei M.R. (1997)). An interphase area is the most important factor for complete cleaning. Usually the unit for wet cleaning consists of two stages equipment in industrial applications. The first stage is frequently created by Venturi scrubber or homogenizer "O-element". A packed column comprises the second stage very often.

The homogenizer "O-element" design is shown in Figure 2. Large surface area is achieved by the frontal impaction of two streams (two phase mixtures of flue gases and absorption liquid). In this place occurs so called "transition phenomenon".

The advantage of this equipment is a lower pressure drop compared to Venturi scrubber whilst maintaining the same efficiency of wet cleaning. Lower pressure drop can notably reduce investment and operation costs for transport of flue gases in industrial plants.

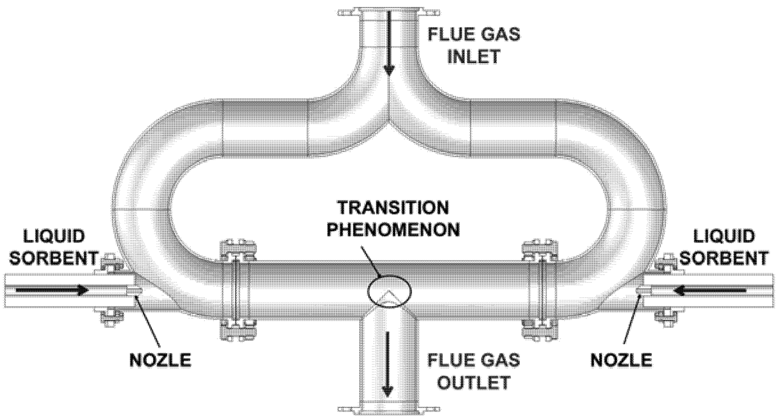

Figure 2 Equipment for wet cleaning of flue gases

2.3 Combined experimental equipment for cleaning of waste gases polluted by solid particulates, SO_2, HCl, HF and heavy metals (alternatively NO_X or PCDD/F)

Combined experimental equipment (see Figure 3) has been developed to verify the technology for cleaning of flue gases in chemical and process industry, mainly the following processes of flue gases cleaning: filtration/catalytic filtration of solid particulates and PCDD/F (Peltzoldt (2005)), dry cleaning of flue gases – i.e. reaction of SO_2, HCl and HF with injected adsorbent $NaHCO_3$, adsorption of VOC, heavy metals and PCDD/F on a layer of active carbon (Yun, J. (1997), Chahbani M.H. (2001)) and selective catalytic reduction NO_X (SCR).

Developed experimental equipment is designed for a process with capacity of 1000 m^3/h of waste gas (flue gas) at max. temperature of 250°C and will be connected to a process with a underpressure of about 10 kPa. Maximum processed levels of pollutants are as follows: solid particulates – 2 g/m_N^3, VOC – 500 mg/m_N^3, SO_2 – 2,000 mg/m_N^3, HCl – 1,000 mg/m_N^3 and HF – 50 mg/m_N^3.

Design of this experimental equipment is rather specific. The most important feature is its mobility and its installation directly at industrial plants. For this reason, it is a stand alone equipment and apart from connection to the power line (~400V/63A) and standard mains of water, it is completely self-sufficient. From a design point of view, the experimental equipment has been divided into filter, replaceable side modules and drive unit.

Filter contains 15 filter bags with a diameter of 152 mm and is 2,500 mm long. The pulse-jet cleaning with pressure air is used for a regeneration of the filter bags. The equipment was designed on the base of required filtration area. For processing of gas with real flow rate of 1000 m^3/h and selected air-to-cloth ratio of 55 m/hr is required filtration area about 18.2 m^2. This value was used for proposing of number and dimensions of the filter bags. Two replaceable modules are placed on each side of the filter. These modules can be adapted for adsorption process of waste gas, or for storage of a catalyst for selective catalytic reduction NO_X (SCR). The dimensions of adsorption modules were proposed on the base of superficial velocity, which should range between 0.1 m/s and 0.5 m/s for layer of activated carbon (AC) with height of 0.5 m. We decided for layer of AC with height of only 0.25 m and therefore the lowest value of recommended superficial velocity was used. (The reason for lower height of layer came from the requirement of compatibility of the whole equipment). For these conditions the value of adsorption area of 3.5 m^2 was calculated. The last part of the experimental equipment is so-called drive unit, which will supply transport of waste gas and pressure gas for

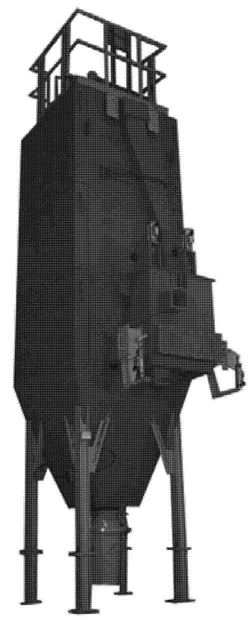

Figure 3 Equipment filtration/adsorption (SCR)

pulse-jet regeneration of filter bags. This module also contains adsorbent injection system (especially for sodium bicarbonate), and can also be further equipped with a liquid injection system (injection of NH_2-X compounds).

The main contribution of an experimental multifunctional equipment is that individual technologies for off-gas reduction can be tested, modelled, and optimized directly in operation mode, i.e. without previous laboratory analysis and scaling-up. The experiments with the aim to remove several pollutants simultaneously will be performed in this unit. It is able to reduce various kinds of harmful compounds. The wide range of applications of proposed design is obvious from Figure 4.

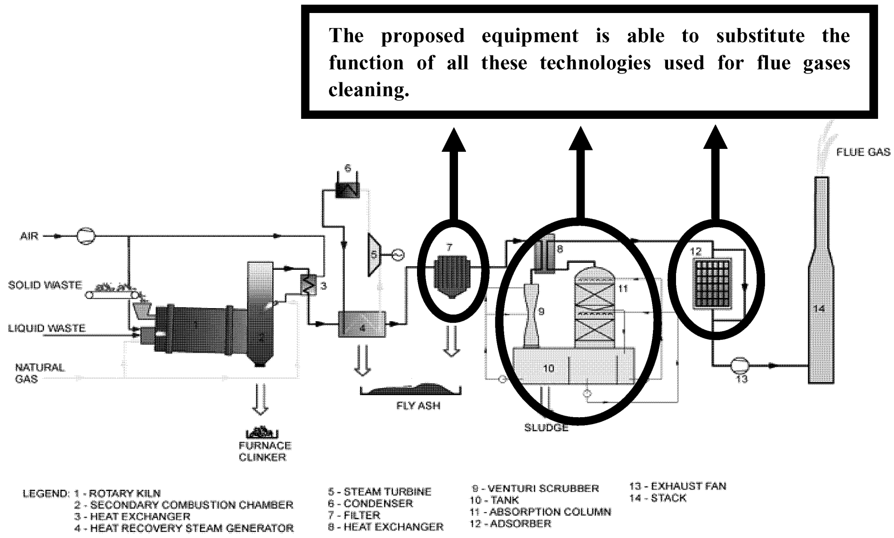

Figure 4 Flowsheet of common technologies used for thermal treatment of solid and liquid waste

3. Conclusions

Three units proposed for off-gas and flue gases cleaning were developed. At the same time pilot equipment were designed and realised. They are able to test developed technologies. From experimental measurements data indispensable for modelling and designing of analogous devices used in industrial conditions were obtained. There were realised four applications of equipment for thermal and catalytic treatment of waste in chemical and food industry (see Figure 5). We plan to test another two types of the developed equipment under industrial conditions in the nearest future.

Figure 5 Equipment for the thermal treatment of off-gas from the smoked meat production

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