WASTE HEAT USAGE IN ASPHALT PLANTS AN EXPLORATORY STUDY

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ABSTRACT

In the next decade energy savings and carbon emission reductions will be a main issue for asphalt plants. Using sustainable materials, cleaner technologies and more efficient processes in order to reduce the energy consumption, and with that the carbon footprint, has become of main importance for every company.

Due to the high humidity levels of many of the raw materials or aggregates before being mixed, a considerable amount of the heat destined to bring the materials to mixture temperature, is lost due to the evaporation of this moisture. The remaining heat of the mixing process is blown off into the atmosphere.
A feasibility study showed that using waste heat from its own flue gasses (or from an external waste heat source) for pre-drying the aggregates, an asphalt plant can reduce the natural gas usage at up to 35%. To do so the existing plant can be extended with a low-temperature drying installation. By taking advantage of national tax reductions for energy saving investments and a good financing plan, the payback period is as short as 5 years.

In terms of carbon emissions, this project complies with the multi-year agreement on energy efficiency (MJA3) of the Dutch government for CO2 emission reductions.

Keywords: Energy, CO2-reduction, Cost Reduction, Carbon Emission Reduction

1 INTRODUCTION

The asphalt industry uses fossil fuels for heating the asphalt mixture during the production process and is therefore an emitter of CO_2, one of the greenhouse gases causing global warming. At this point, the scientific consensus is that this very likely leads to global warming. With possible effects such as flooding, drought, food shortage and reduction of biodiversity, public authorities have committed themselves to ambitious CO_2-reduction schemes and even set goals for Carbon Neutral Solutions in the (near) future. The exhaust of oil- and gas resources and the geopolitical aim to become less dependent on imports also plays a role. Therefore, striving for a reduction of energy used and with that the amount of CO_2 emitted could become an interesting business opportunity for the asphalt industry in the years to come. According to the World Business Council for Sustainable Development (WBCSD) distinct competitive advantages can actually be achieved when being dedicated to finding a balance between business performance and environmental and social responsibility, as long as they are based on solid ethical principles (1).

Research conducted by the Dutch Economical Institute for SME's (EIM) amongst 1663 SMEs with between 2 and 250 employees has concluded that more than three quarters of the industrial SME's, to which also asphalt plants belong, are currently working on implementing energy saving measures (2). Another interesting finding is that more than half of the firms have noticed that an increasing amount of clients are placing more severe restrictions on environmental conduct.

The aim of this paper is to provide the reader with a framework in order to understand the recent push for sustainability, described in further detail below. Furthermore, the contents of this paper will quantify how innovative asphalt plants can capitalize on sustainable development. The second half of the paper focuses on a promising technical solution; the implementation of waste heat re-usage in asphalt plants, which the authors of this paper have been researching for several years now.

2 EMISSION REDUCTIONS AND ENERGY SAVINGS

2.1 Europe

The need to make better use of our limited natural resources has resulted in energy-efficiency becoming one of the major pillars of the European Union (EU) in its 2020 strategy for smart, sustainable and intelligent growth (3). Energy Efficiency, which can be defined as the reduction of energy input whilst maintaining an equivalent level of economic activity or provision of services, is one of the most cost-effective ways of improving Europe's security of supply and reducing the emission of greenhouse gasses and other contaminants. This is the reason why the European Union has set the ambitious goal of reducing its primary energy use by 20 % by the year 2020 (4).

For small and medium-sized enterprises, like asphalt production plants, the greatest hurdle that needs to be taken in order to acquire the necessary technology to achieve higher energy efficiencies is finance (5). The European Union aims to encourage member states to provide SME's with information (e.g. with regard to laws and regulations, criteria which need to be met for subsidies, the availability of energy management related education) and to develop specifically tailored stimuli (tax reductions, beneficial financial constructions for investments in energy efficiency or providing means for executing energy audits). In cooperation with the different industrial branches the European Union has plans to support the exchange of best practices in the field of energy efficiency and to execute projects aiming to expand the energy management capacity in very small and small enterprises. Furthermore, the European Union will support the development of tools that enable the SME's to compare their energy usage with similar companies (6).

At industry level, the European construction industry has expressed the vision that research, development and innovation in the construction sector can make a significant contribution to a sustainable world. The European Network of Construction Companies for Research and Development (ENCORD), founded in 1989 and representing an industry-led innovation network comprised of the twenty leading European construction firms, recently signed a Sustainable Development Charter (7). All participating companies will integrate the principles laid down in the charter in their operations and will exchange best practice experiences, including on how to best reduce CO_2 emissions. Furthermore, they will compute a means for translating the charter into an action plan which will be presented to a 2,000 participant audience at the World Sustainable Building Conference 2011.

2.2 The Netherlands

2.2.1 MJA-3

The Dutch government, supporting the EU-push to secure Europe's energy future, recognizes that in order to achieve a sustainable energy supply, energy savings are most important. In order to stimulate energy savings in the Dutch industry, the so called multi-year agreements (Meer Jaren Afspraken, MJA) were developed (8). This is an arrangement between the government and the industrial sector. In the latest agreement (MJA-3), which acts as a continuation of the MJA-2, the government, trade and industry have enclosed targets concerning energy savings and energy efficiency improvements. An improvement of MJA3 over the MJA2 is that only the actually implemented measures are considered as results. In the MJA-2 other influences were also taken into account. This is more in line with national and international guidelines as sector wide improvements are now excluded from participation. As a result of this, the efforts of individual firms are more easily determined.
To participate in the MJA-3 both the sector and the individual firms have to meet a number of requirements. Firstly, a participating inter-branch organization is obliged to stimulate its members to participate in the MJA and to draft a 4 year plan for the industry as a whole with respect to its energy efficiency. Secondly, any firm operating within this trade organization, who signs the covenant, is compelled to write a 4 year energy-efficiency plan (EEP) and to publish an annual report on its progress. Next to these obligations, a number of targets are included in the MJA-3. The most important ones being:

- A total average Energy Efficiency Improvement (EEI) of 30 % for the participating corporations in the period from the beginning of 2005 to the end of 2020.
- An EEI of 8 % per corporation in the period 2009-2012.

(The EEI is related to the energy use in the EEI-base year. For the period 2009-2012 the base year has been determined to be 2008, unless a definitive argumentation is presented to deviate from this approach.)

New in the MJA-3 approach is also the so called 'company approach'. During the MJA-1 and MJA-2 period, a lot of (small) measures were taken to improve energy efficiency and energy savings. In order to proceed, today a much higher level have to be reached. In most cases this can only be achieved by more structural measures and therefore this often means big(ger) investments. In the Netherlands large construction companies often own more than one asphalt plant. In order to spread the financial burden and to enable more significant changes the government therefore introduced the so-called 'company approach', whereby not all the asphalt plans operating within a large corporation have to improve individually (regarding to energy savings and –efficiency). Instead, they are allowed to take measures only at one plant, as the energy (efficiency) savings that are generated here will be counted as an overall energy reduction. This approach allows more structural measures, whilst not increasing costs significantly for the MJA-3 members. In this way, an overseeing institution can choose to realize the energy savings where they are most beneficial (9).

2.2.2 CO_2 Performance Ladder

In 2009 Prorail, a company responsible for most of the rail infrastructure in the Netherlands, developed an instrument called the CO_2 Performance Ladder to stimulate its suppliers to reduce their CO_2 emissions when tendering for a Prorail project. The primary focus points of this ladder are energy savings, the efficient use of materials and the utilization of sustainable energy sources. Prorail does not regulate production or product methods. The way how these environmental goals are realized is completely up to the applicants (10).
With the ladder, Prorail wants to stimulate creativity and renovate existing concepts of management and products (11) by taking into account what position tendering organizations have on the ladder (level 1 being the lowest and level 5 being the highest position). The higher the position on the ladder the bigger the assigned benefit of a fictitious discount in the tendering process, varying from 1 % up to 10 %. So, in the end the ladder has a significant influence on the system of Economically Most Profitable Application (EMPA).
After a year of experience, a second version of the CO_2 Performance Ladder was developed, with several practical improvements and clarifications, but also more widely applicable than only for the railroad sector (12). It is widely expected, that this will lead to the situation in which contractors not only have to make complete CO_2-calculations of their building activities in advance but, during execution of the allotted work, have to prove that they will not transcend these CO_2 amounts. Unless willing to be confronted with significant penalties. Naturally, this also includes the amount of CO_2, emitted at an asphalt plant, where asphalt is produced for a roadwork.
A medium sized asphalt plant in Amsterdam (APA) states that on average their CO_2 reductions are profitable up to a reduction of approximately 20 % (9). Further CO_2 mitigation reduces the firm's competitiveness and would therefore lead to loss of market share. Hence, if any company is ever to achieve a 100 % reduction, clients will need to attribute

value to the sustainable production methods. Therefore, if a significant portion of the annual revenues could be generated by orders from clients who are known to accredit value to sustainable production (TNT, the national government, municipalities and semi-government institutions like Prorail) it would be possible for asphalt production plants, operating within the parameters of the company approach, to produce in a fully sustainable manner.

3 THE ASPHALT ENERGY LIFE CYCLE

Miller and Bahia (13) define the system boundaries of the asphalt cradle to cradle lifecycle as seen in figure 1. They also analyze the share in energy consumption and GHG emissions for each of the sub processes. Fuel usage for the extraction of raw materials is found "to *impose minimal energy requirement relative to the other processes in the asphalt life cycle* ". The production of bitumen however, is an energy-intensive process, as it represents 40 % of the total lifecycle energy use. However, it is considered to be part of procurement and therefore does not play a role in this paper. The largest share of the system wide energy consumption is the asphalt manufacturing process (50 %). The energy used for construction is stated to be minimal and maintenance "*is often considered the least energy-intensive process*". The final stage of the lifecycle is the removal of the pavement and its subsequent reentrance into the manufacturing process as granulate recycled asphalt.

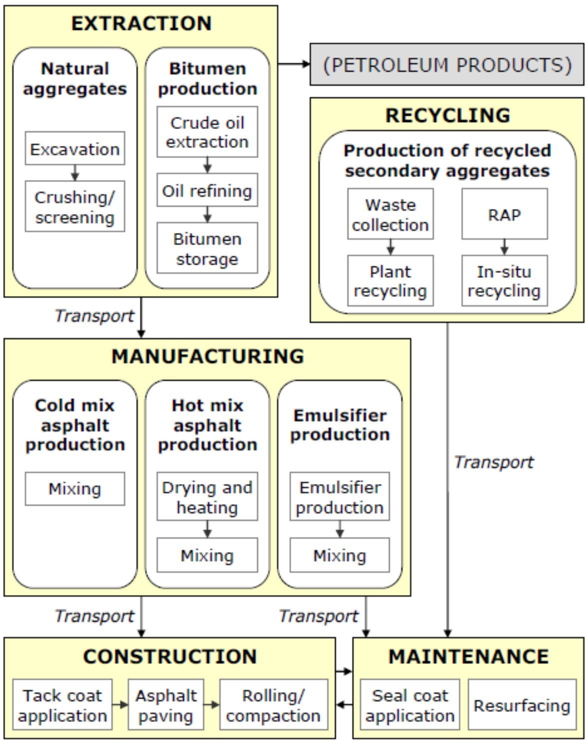

Figure 1. Five main processes comprise the system boundaries for the asphalt pavement life cycle analysis. This analysis excludes petroleum products (13).

In figure 2 the energy use of a medium sized asphalt plant in Amsterdam (APA) is shown, producing roughly 350.000 tons of asphalt per annum in small batches. It shows that a portion (8 %) is used for the hot storage of bitumen. Mixing and dust removal together are responsible for another 6 %. Crushing and sieving old asphalt chunks takes 21 %. But most of the energy (63 %) is used for drying and heating the aggregates, by far the most energy-intensive part of the life cycle.

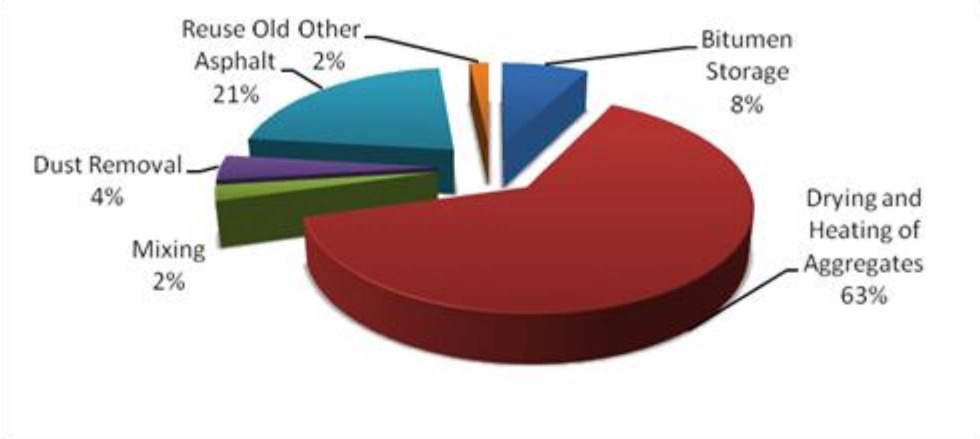

Figure 2. Energy balance of an asphalt plant (9)

4 THE BENEFITS OF ENERGY SAVINGS IN ASPHALT PRODUCTION

4.1 Energetic benefits

An extensive thermodynamic analysis by Peinado et al. (14) shows that there is an inevitable efficiency loss in the drying process of hot-mix asphalt (HMA). Figure 3 shows the relation between humidity, hot mix temperature and the energy requirement. The black dot indicates a typical situation. For a typical plant, the paper finds a value of 8.21 kWh or ~30 MJ, or ~1 m^3 natural gas per % point humidity *increase* per tonne asphalt produced. Calculating this energy usage in terms of natural gas, a value of **3.39 GJ/ tonne of water** is obtained (*note: The latent heat for vaporization of water is 2,260 GJ/tonne of water*). This amounts to a use of 107 m^3 of natural gas per tonne of water in the aggregate that is needed to evaporate the water, So each tonne of water that is no longer in the aggregate because it has been pre-dried, (or because the water didn't enter the materials in the first place) saves 107 m^3 of natural gas.
In the low-temperature range (0-100°C), the energy needed to heat the aggregate, is ascertained by means of the specific heat of the aggregate. This specific heat is calculated by weighing the specific heat values of the sandstone, gravel, (recycled) asphalt and water, the three main components of (wet) feedstock. This yields a value of **1.05 MJ/ tonne of aggregate * degree Celsius**. Therefore, if the aggregate are pre-heated this energy for heating can be saved in the production process.

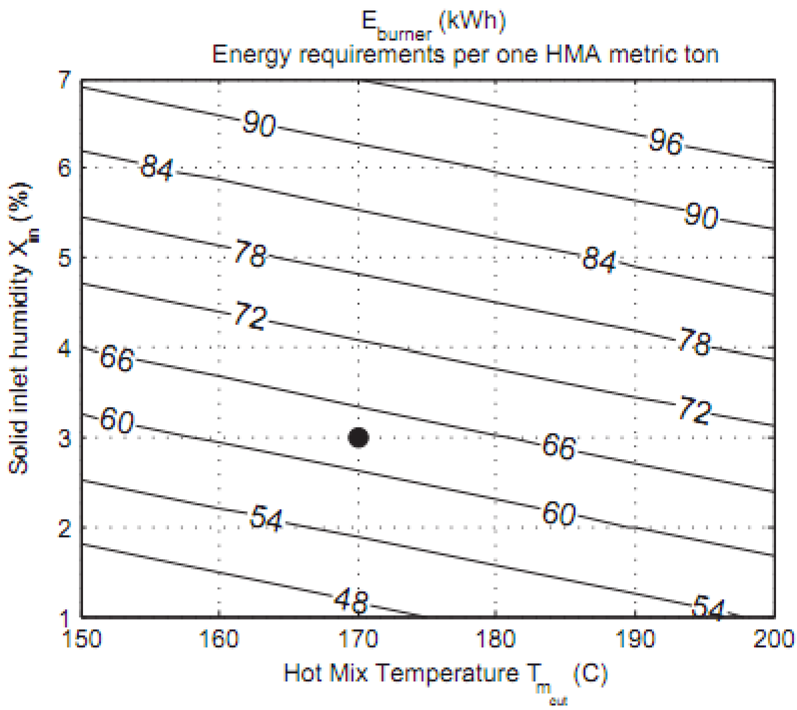

Figure 3. The relation between humidity, hot mix temperature and the energy requirement (13)

4.2 Economic Benefits

The economic benefits of natural gas savings depend on the natural gas price. For big industries like the asphalt industry however, a vast share of the annual gas costs are fixed, and the price per cubic meter only accounts for a certain share of the total gas costs. An asphalt plant in Tiel (ACR) for instance, situated centrally in the Netherlands, has a gas contract where variable costs per m^3 only make up 53,5 % of the total price paid for the gas (15). The remaining costs are taxes and infrastructure costs, which are more or less fixed. Energy reports of APA and ACR show average gas prices over the last few years of 28.7 and 29 Eurocents per m^3 respectively. Assuming similar contracts, with a variable component of 53.5 %, this leads to a variable gas price of € 0,15/m^3 of natural gas.

Looking at the numbers generated in the previous paragraph, this implies the following costs

- **16.05 € / tonne of water** for drying, and
- **0.5 € cents / tonne of aggregate * degree Celsius** for heating.

4.3 Environmental Benefits

The emission factor of natural gas is 56 kg CO_2/ GJ. This implies an emission of **189.6 kg CO_2/ tonne of water** for the drying, and **0.059 kg CO_2/ tonne of feedstock * degree Celsius** for the heating process.

4.4 Subsidiary Benefits

A currently ongoing joint investigation by the APA, the port authority of Amsterdam, the nearby waste-incinerating-power-plant (AEB) and BreedofBuilds aims to realize an installation where the use of primary energy use can be reduced. The goal of this project is to achieve energy reduction in the asphalt plant by utilizing process waste heat, which can be rerouted to preheat the mineral aggregates.
The project is a continuation of a successful feasibility study supported by the Sustainability and Innovation Fund of the Port of Amsterdam; a fund specifically aimed at supporting sustainable development and innovation initiatives in the Amsterdam harbor area. As a result of the project having reached the development phase, it is entitled to a 37,5 % subsidy, with the maximum remitted sum amounting to € 200.000 (16)
For the Port of Amsterdam the future perspective is that this project, can contribute to the realization of a waste heat grid, using waste heat from the waste-incinerating-power-plant or the coal-fired-power-plant which are both located in the harbor area. The waste heat can also be adopted by other companies who wish to moderate their energy usage. In this way a synergetic relationship can be established between heat producing and heat demanding companies.
Furthermore, as of 2010, the Dutch government has started stimulating the use of waste heat by means of subsidies. Business cases that aim to effectively use waste heat may receive subsidies up to 50 % of the costs with a maximum of 100.000 Euro per request (17).

5 WASTE HEAT SOURCES

There are many different techniques to reduce the energy intensity of the asphalt production process. These techniques range from solutions to produce asphalt at lower temperatures (technically possible, but qualities are different) to just covering the aggregates with a roof to prevent rainwater from further increasing the moisture content of the feedstock. This paper focuses on one interesting technique being the utilization of waste heat in the asphalt plant.

5.1 Internal Waste Heat:

Under normal operating procedures, a mixing drum is used for the evaporation of water and heating the aggregates. From an exergetic point of view, it is inefficient to evaporate water at temperatures above 150 °C (as is currently done in asphalt plants) when it can also be done at much lower temperatures. Evaporation, to a certain extent, already occurs at ambient temperatures and can be stimulated by purely mechanical, non-energy-consuming means or by ventilation and warming the air to temperatures significantly below 100 °C. So, the efficiency of the manufacturing process might be increased by influencing the drying temperature.
Heat at around 70 °C needed for the drying process may be taken from the asphalt plants own flue gasses. These flue gasses are exhausted via the chimney at temperatures usually at around 100 °C. The flue gasses contain in the order of 9

MW of heat power. Most of it being latent heat which is released when the water condensates. Because of the humidity of the flue gasses, a heat exchanger is required to make use of the relatively dry ambient air.

5.2 External Waste Heat

Heat for drying and heating the aggregates can also come from external waste heat sources. Asphalt plants in the Netherlands are usually located in zones where heavy industry is clustered. Many other heavy industry types produce excessive heat during their production processes, which can be recovered for the use in an asphalt plant. Apart from the APA which could utilize the waste heat from nearby power plants, the ACR is located only 700 meters from a glass factory (AGC Flat Glass) which emits flue gasses at temperatures of around 200C. These temperatures are higher than the asphalt production process requires. Many asphalt plants are situated under similar circumstances and should therefore scan their direct environment for compatible energy streams.

6 APPLYING RECOVERED WASTE HEAT

As explained previously, from an exergetic point of view, it would be better to dry at lower temperatures. Also the option of using waste heat from external sources was discussed. The question now is how to get this heat into the production process. In this chapter several options are discussed.

6.1 Combustion Inlet Air Heating

One way to use a hot air flow is to preheat the air entering the mixing drum. At the APA the maximum amount of heat extractable from the chimney is coincidentally precisely enough to heat the air which is sucked into the burner for the combustion of natural gas. The mixing drum burner of the APA plant requires approximately 60.000 m^3 of air per hour. As explained, flue gasses of asphalt plants have temperatures of around 100 °C. Depending on the price of the heat-exchanger, the possibilities to deal with condensation-water and the efficiency of the heat exchanger, this investment is feasible.

If all the inlet air-flow at APA could be heated from 10°C to, let's say, 80°C before entering the two mixing drums, the estimated energy savings can be up to a theoretical maximum of **12 %** or **747 tonne CO_2/year**. Using an external heat source is also possible.

6.2 Pre-Drying Chamber

Another technique studied for drying aggregates is by utilizing a drying chamber. Feedstock is in this case stored in a separate chamber where it is ensured the feedstock has a decent exposure time to the reused hot air. Drying rates of drying chambers are highly dependent on the type and their design and the exposure time. Many drying chamber types are available and are used for industrial processes (18). The disadvantage of a drying chamber is that the aggregate is not available for production as long at it remains the drying chamber.

Theoretically, if exposure times are long enough and by using a CO_2 emission free external heat source, the estimated energy savings can up to **35 %**, or **2212 tonne CO_2/year.**

6.3 Conveyorized Pre-Drying system

To ensure a continuous production process and an optimum heat transfer process, a conveyorized drying system is a good alternative. If large enough, the majority of moisture can be extracted from the feedstock. As the production process of the asphalt plant is discontinuous, aggregates that are already laid upon the conveyor belt get extra timeframes for drying. This is an advantage of this technique. To ensure enough drying time these drying-systems can get quite large, up to 100 meters long. If the heat itself can be delivered at a low price, the investment would definitely be worthwhile.

By using a CO_2 emission free external heat source, estimated energy savings can be around **20 %,** or **1202 tonne CO2/year.**

6.4 Bitumen-storage heating with waste heat

Bitumen need to be stored at temperatures of around 180 °C. The storages are generally heated using thermal oil, which in turn is heated by gas incineration. Another option is using electrical heating. If a heat source of around 200 °C is available, utilizing it for this purpose is definitely a good option.
Estimated possible energy savings in the asphalt plant can be as high as **8 %**, which equals the total energy usage for bitumen heating.

6.5 Heating the office-buildings with waste heat

For heating the modest office buildings of an average asphalt plant around 20kW is needed, which is not that much. Excess waste heat, which does not find any use in one of the above mentioned major applications, can be rerouted to service this need.
Estimated energy savings can be around **0.2 %**, or **13 tonne CO2/year**

7 CONCLUSION

Energy reduction is getting increasingly important for asphalt plants. Energy costs are high and an increasing social need and market pressure is experienced to reduce CO_2 emissions.
There are several good options to use waste heat in an asphalt plant to reduce energy usage. Waste heat usage is potentially the best way to save energy in asphalt plants. Feasibility studies have shown that recovering and using waste heat, from either an internal or an external source, can reduce natural gas usage by as much as 35 % in the asphalt plant. An additional benefit is that the installations required can be built as an extension to existing plants, so production processes remain undisturbed. The required modifications to the existing installations are mostly minimal. As demonstrated the cost reductions can be substantial and by taking advantage of national tax reductions and local and national subsidies for energy saving investments, it might very well be possible to create a feasible financial plan for the implementation of these techniques. The reduction in carbon emissions will allow an asphalt plant, participating in a tender involving the CO_2 performance ladder, to make a competitive bid, being able to outperform a large part of the competition on environmental responsibility. Moreover, all major measures proposed are good alternatives for complying with the multi-year agreement on energy efficiency (MJA3) implemented by the Dutch government.

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