Quantitative Evaluation Method for Greenhouse Gas Emissions in Asphalt Pavement Construction Stage

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Abstract—The paper has studied on how to quantitatively evaluate greenhouse gas emissions during asphalt pavement construction. The calculation method is put forward, and the greenhouse gas emissions during the construction of asphalt pavement are obtained. Through calculating examples, the paper got energy saving and emissions reduction effect of warm mix asphalt, at the same time, and drew conclusions of effects of different mixing equipment and transportation equipment on total greenhouse gas emissions. The paper got some good conclusions through the calculation data: the raw material production process accounts for 13% of the total emissions; while asphalt mixture mixing, paving and rolling accounted for 67% of the total emissions, of which about 60% were in the asphalt mixture mixing stage alone. Transport processes account for 20% of total emissions. Compared with warm mix asphalt, heat mix asphalt reduced emissions by 18.2%. The main influencing factor of greenhouse gas emissions in the transportation process is the ratio between diesel consumption of transport equipment in one hundred kilometers and the maximum freight volume of the transportation equipment.

1. INTRODUCTION
The transportation industry accounts for a large proportion of greenhouse gas emissions all round the world, it accounts for about a quarter of global greenhouse gas emissions. In China, the transportation industry accounts for eight percent of the total emissions of pollutants and greenhouse gases [1]. From 1981 to 1990, the global average temperatures have risen 0.48 degrees 100 years ago. Global temperature estimation would rise by about 1.4 to 5.8 degrees Celsius. Global temperatures will appear in the past 10000 years never had the huge change, which bring significant impact on the global environment [2]. Between 1970 and 2004, annual CO2 emissions have increased by about 80%, from 21 to 38 billion tons [3]. In 2014, anthropogenic greenhouse gas emissions accounted for 77% of all emissions [4]. Therefore, the main direction of efforts to mitigate climate change, is to reduce carbon emissions.

From the 1990s, many countries have conducted research to reduce greenhouse gas emissions. At present, the most widely used method is LCA. LCA was used in road construction and maintenance process by Swedish Environmental Research Institute [5]. EAPA used LCA in reclaimed asphalt pavement, including the process from refining to storage. Howard and Edwards established BRE method environmental profiles of construction materials, components and buildings [6]. Yue and Roger developed LCA model for reclaimed asphalt pavement [7]. Horvath developed pavement Life-Cycle assessment tool for environmental and economic effects, this tool focus on road material recovery and disposal [8]. Burnham developed models for evaluating emissions from various fuels [9]. Philip and Jay established a model for different the impact of different roads on climate [10].
Although these LCA models established framework and database in pavement engineering, there are still many shortcomings. BER model has low correlation with asphalt, Horvath’s model is only used in hot mix asphalt process, model which is developed by Philip can not apply in reclaimed road works. At the same time, one LCA model for one country cannot be applied to another country. There are some differences between material, construction technique, data validity and applicability. LCA lacks refinement, simplicity and efficiency, and it cannot apply in China. According to the construction characteristics of China, a new quantitative evaluation method of greenhouse gas emission should be proposed.

The paper put forward the calculation method of greenhouse gas emissions in asphalt pavement construction stage by using quota. By analyzing characteristics of raw materials production process, transportation process and site construction during asphalt pavement construction stage, the measurement index is selected within the evaluation boundary of greenhouse gas emissions. Use the quota method to determine greenhouse gas emissions. Greenhouse gas emissions of various emission sources are measured.

2. CALCULATION METHOD OF GREENHOUSE GAS EMISSIONS FROM ASPHALT PAVEMENT

2.1. Definition of Research Scope
The paper, our research scope includes production process of raw materials, asphalt mixture construction process and transportation process. The production process of raw materials includes aggregate and asphalt production. Asphalt mixture construction process includes mixing, paving and rolling of asphalt mixture. Transportation process includes transportation of raw materials during production, site construction and transportation of asphalt mixture. According to Kyoto Protocol, The paper used six types of greenhouse gases (CO₂, CH₄, N₂O, HFCs, PFCs, SF₆) for accounting carbon dioxide equivalence. These six greenhouse gases are converted to carbon dioxide equivalent.

2.2. The Research Methods
The calculation method has the following steps:
- The determination of calculation parameters: the emissions source is divided into three aspects: raw materials, mechanical equipment and transportation equipment.
- The selection of quota: there are many quotas in different provinces, it will affect outcomes. Choosing adapt quota.
- Calculation of data: total greenhouse gas emissions came from that the sum of every emissions source multiplied by its per unit greenhouse gas emissions.

3. CALCULATION OF GREENHOUSE GAS EMISSIONS IN ASPHALT PAVEMENT CONSTRUCTION STAGE

3.1. Scheme Introduction
This project is a surface engineering of highway construction. The length is 49.503km, the starting pile is K38+000 and the ending pile is K87+503. The structure of surface layers is 4cm SMA-13, 6cm AC-20 and 8cm AC-25, the width of pavement is 30m. The location of stone material factory is K38+200. It is 17 km apart from the route. The location of four asphalt mixture plants are K53+000, K38+200 and K38+550 and K54+400. They are 0.5km, 20km, 0.5km and 0.5km apart from the route. Trucks with a load capacity of 10t and 15t are used during transportation process.

Quantity of lower layer is 59403.6m³, quantity of middle layer is 89105.4m³, quantity of upper layer is 118807.2m³.

The data were collected on the spot. Per kilowatt hour of electricity carbon dioxide equivalence emissions was replaced by 0.361 kg of coal’s. So, every kilowatt hour of electricity will produce 0.92 kg carbon dioxide equivalence emissions.
Burning a liter of diesel will produce 11.56 kg carbon dioxide equivalence emissions.

3.2. Calculations of Greenhouse Gas Emissions

3.2.1. Greenhouse gas emissions of raw materials

The density of sand is 1350kg/m³, the density of aggregate chips is 1400kg/m³, The density of gravel is 1450kg/m³.

**TABLE I. QUANTITIES OF RAW MATERIALS GREENHOUSE GAS EMISSIONS**

| Designation        | Quantity    | Unit   | Per Unit Emissions | Total Emissions   |
|--------------------|-------------|--------|--------------------|-------------------|
| Asphalt            | 23330.79t   | 1 t    | 12.19kg            | 284607.67kg       |
| Sand               | 55823.64m³  | 1 m³   | 7.39 kg            | 435297.58 kg      |
| Mineral Powder     | 14998.60t   | 1 t    | 7.39 kg            | 110918.02 kg      |
| Aggregate Chips    | 50240.89 m³ | 1 m³   | 7.39 kg            | 406274.63 kg      |
| Gravel(1.5cm)      | 129247.38 m³| 1 m³   | 7.39 kg            | 1082490.5 kg      |
| Gravel(2.5cm)      | 85010.71 m³ | 1 m³   | 7.39 kg            | 711993.42 kg      |
| Gravel(3.5cm)      | 71229.66 m³ | 1 m³   | 7.39 kg            | 596572.55 kg      |
| **Total**          | -           | -      | -                  | 3628154.41 kg     |

Quantities of raw materials greenhouse gas emissions are totally 3628154.42kg carbon dioxide equivalence. Among them, the production greenhouse gas emissions of asphalt production process is 284607.67kg carbon dioxide equivalence, the production greenhouse gas emissions of aggregate production process is 3343546.75kg carbon dioxide equivalence.

3.2.2. Greenhouse gas emissions of mechanical equipment

The following tables are about calculations of quantity, per unit mechanical equipment greenhouse gas emissions and total greenhouse gas emissions during paving and compaction process.

**TABLE II. QUANTITIES OF PAVING AND COMPACTION PROCESS**

| Designation            | Emissions of Carbon Dioxide Equivalence |
|------------------------|----------------------------------------|
| 3.0m³ Wheeled Loader   | 664.13 Machine-Team                    |
| 6-8t Static Roller     | 761.55 Machine-Team                    |
| 12-15t Static Roller   | 1137.28 Machine-Team                   |
| 9.0m Asphalt Paver with Self-leveling | 386.42 Machine-Team             |
| 9-16t Wheel Roller     | 740.76 Machine-Team                    |

**TABLE III. QUANTITIES OF PER UNIT MECHANICAL EQUIPMENT DURING PAVING AND COMPACTION PROCESS GREENHOUSE GAS EMISSIONS**

| Designation            | Unit           | Emissions of Carbon Dioxide Equivalence |
|------------------------|----------------|----------------------------------------|
| 3.0m³ Wheeled Loader   | 1 Machine-Team | 916.71kg                               |
| 6-8t Static Roller     | 1 Machine-Team | 370.76kg                               |
| 12-15t Static Roller   | 1 Machine-Team | 465.99kg                               |
| 9.0m Asphalt Paver with Self-leveling | 1 Machine-Team | 939.75kg                        |
| 9-16t Wheel Roller     | 1 Machine-Team | 591.13kg                               |
TABLE IV. QUANTITIES OF MECHANICAL EQUIPMENT DURING PAVING AND COMPACTION PROCESS GREENHOUSE GAS EMISSIONS

| Designation                          | Emissions of Carbon Dioxide Equivalence |
|--------------------------------------|-----------------------------------------|
| 3.0m³ Wheeled Loader                 | 608817.30kg                             |
| 6-8t Static Roller                   | 282353.23kg                             |
| 12-15t Static Roller                 | 529969.77kg                             |
| 9.0m Asphalt Paver with Self-leveling| 363136.41kg                             |
| 9-16t Wheel Roller                   | 437889.97kg                             |
| Total                                | 2222166.71kg                            |

Quantities of paving and compaction greenhouse gas emissions are totally 2222166.71kg carbon dioxide equivalence.

Quantities of mechanical equipment greenhouse gas emissions are totally 18754419.59kg carbon dioxide equivalence.

3.2.3. Greenhouse gas emissions of transportation equipment.
Choosing the following types of transportation equipment.

TABLE VI. THE DIESEL CONSUMPTION AND GREENHOUSE GAS EMISSIONS OF THE TRANSPORT EQUIPMENT IN ONE HUNDRED KILOMETERS

| Type            | Full Load | No-load | Emissions of Carbon Dioxide Equivalence |
|-----------------|-----------|---------|-----------------------------------------|
| 13t Dump Truck  | 20.20L    | 18.30L  | 105.64kg                                |
| 15t Cargo Vehicle| 21.60L    | 18.40L  | 109.76kg                                |
| 15t Dump Truck  | 17.70L    | 15.20L  | 90.28kg                                 |
TABLE VII. LOAD DISTANCE OF AGGREGATE TRANSPORT AND GREENHOUSE GAS EMISSIONS

| Destination          | Load Distance | Emissions of Carbon Dioxide Equivalence |
|----------------------|---------------|-----------------------------------------|
| Asphalt Mixture plant I | 794714.92km   | 839589.89kg                             |
| Asphalt Mixture plant II | 679349.98km   | 717710.67kg                             |
| Asphalt Mixture plant III | 827466.49km   | 874190.83kg                             |
| Asphalt Mixture plant IV | 2945855.70km  | 3112198.62kg                            |
| Total                | 5247387.09km  | 5543690.01kg                            |

TABLE VIII. LOAD DISTANCE OF ASPHALT TRANSPORT AND GREENHOUSE GAS EMISSIONS

| Destination          | Load Distance | Emissions of Carbon Dioxide Equivalence |
|----------------------|---------------|-----------------------------------------|
| Asphalt Mixture plant I | 8789.83km     | 7935.45kg                               |
| Asphalt Mixture plant II | 5093.46km     | 4598.37kg                               |
| Asphalt Mixture plant III | 9397.89km     | 8484.41kg                               |
| Asphalt Mixture plant IV | 41590.54km    | 37547.89kg                              |
| Total                | 64871.72km    | 58566.12kg                              |

TABLE IX. LOAD DISTANCE OF ASPHALT MIXTURE TRANSPORT AND GREENHOUSE GAS EMISSIONS

| Destination          | Load Distance | Emissions of Carbon Dioxide Equivalence |
|----------------------|---------------|-----------------------------------------|
| Asphalt Mixture plant I | 27222.89km    | 24576.80kg                              |
| Asphalt Mixture plant II | 27127.13km    | 24490.34kg                              |
| Asphalt Mixture plant III | 28875.23km    | 26068.53kg                              |
| Asphalt Mixture plant IV | 185466.71km   | 167439.13kg                             |
| Total                | 268691.96km   | 242574.80kg                             |

Quantities of transportation equipment greenhouse gas emissions are totally 5844830.93kg carbon dioxide equivalence.

3.3. Summary
Greenhouse gas emissions of this project is 28168838.85 kg carbon dioxide equivalence. The average greenhouse gas emissions per kilometer is 569032.9647 kg carbon dioxide equivalence.
4. COMPARISON WITH DIFFERENT CONSTRUCTION SCHEMES

4.1. Comparison with Warm Mix Asphalt Mixture

The warm mixed asphalt mixture is used to replace the hot mixed asphalt mixture. The temperature of mixed process is 140°C [11]. Diesel consumption of 1t asphalt mixture production is 5.26kg, that is, 6.26L/t diesel consumption rate. Power of mixer is 750kw.

| Quantities of Warm Mixed Asphalt Mixture Production Process Greenhouse Gas Emissions |
|---|---|---|
| Machine-Team | 353.45 | 5508.10kg | 1946839.35kg |
| Lower Layer | 296899.18t | 17.33kg | 5145530.05kg |
| Middle Layer | 221765.52t | 17.33kg | 3843396.21kg |
| Upper Layer | 149055.51t | 17.33kg | 2583266.19kg |
| Total | - | - | 13519031.82kg |

Quantities of warm mixed asphalt mixture mixer greenhouse gas emissions are totally 13519031.82kg carbon dioxide equivalence.

The greenhouse gas emissions in warm mixed asphalt mixture production process was reduced by 18.2% compared with that in hot mixed asphalt mixture production process. As the mixing temperature decreases, diesel consumption decreases, which is the main reason for the emissions reduction.

Figure 2. The Proportion of Greenhouse Gas Emissions in Each Stage
4.2. Comparison with Small Mixer
Three mixers of asphalt mixture within 160t are used to replace one mixer of asphalt mixture within 320t. The type of mixer is LB12000. We got results of asphalt mixture production process carbon dioxide equivalence emissions as fellow table.

| Mixer of Asphalt Mixture within 160t | Quantities | Per Unit Greenhouse Gas Emissions | Emissions of Carbon Dioxide Equivalence |
|-------------------------------------|------------|----------------------------------|----------------------------------------|
| Machine-Team                       | 693.53     | 5508.10 kg                       | 3820032.59 kg                          |
| Lower Layer                        | 296899.18t | 21.84 kg                         | 6484278.09 kg                          |
| Middle Layer                       | 221765.52t | 21.84 kg                         | 4843358.96 kg                          |
| Upper Layer                        | 149055.51t | 21.84 kg                         | 3255372.34 kg                          |
| Total                              | -          | -                                | 18403041.98 kg                         |

Greenhouse gas emissions increased by 11.32% with using of small mixers. This suggests that large-scale production is good for reducing greenhouse gas emissions.

4.3. Comparison with Different Transportation Equipment
We chose the following different types of transportation equipment.
We calculated the diesel consumption and carbon dioxide equivalence emissions of the transport equipment in one hundred kilometers.

| Type          | Full Load | No-load | Emissions of Carbon Dioxide Equivalence |
|---------------|-----------|---------|----------------------------------------|
| 10t Cargo Vehicle | 10.40L    | 9.80L   | 55.43kg                                |
TABLE XIII. Load Distance of Aggregate Transport and Greenhouse Gas Emissions

| Destination          | Load Distance | Emissions of Carbon Dioxide Equivalence |
|----------------------|---------------|----------------------------------------|
| Asphalt Mixture plant I | 1033129.40km  | 572665.73kg                            |
| Asphalt Mixture plant II | 883154.97km  | 489534.60kg                            |
| Asphalt Mixture plant III | 1075706.43km | 596266.26kg                            |
| Asphalt Mixture plant IV | 3829612.41km | 2122761.97kg                           |
| **Total**            | **6821603.21km** | **3781228.56kg**                      |

TABLE XIV. Load Distance of Asphalt Transport and Greenhouse Gas Emissions

| Destination          | Load Distance | Emissions of Carbon Dioxide Equivalence |
|----------------------|---------------|----------------------------------------|
| Asphalt Mixture plant I | 13184.75km   | 7308.33kg                              |
| Asphalt Mixture plant II | 7640.19km   | 4234.97kg                              |
| Asphalt Mixture plant III | 14096.83km  | 7813.90kg                              |
| Asphalt Mixture plant IV | 62385.81km  | 34580.58kg                             |
| **Total**            | **97307.58km** | **53937.78kg**                         |

TABLE XV. Load Distance of Asphalt Mixture Transport and Greenhouse Gas Emissions

| Destination          | Load Distance | Emissions of Carbon Dioxide Equivalence |
|----------------------|---------------|----------------------------------------|
| Asphalt Mixture plant I | 314111.03km  | 35942.92kg                             |
| Asphalt Mixture plant II | 31300.53km  | 35816.48kg                             |
| Asphalt Mixture plant III | 33317.58km  | 38124.54kg                             |
| Asphalt Mixture plant IV | 214000.04km | 244875.32kg                            |
| **Total**            | **310029.18km** | **354759.26kg**                        |

Quantities of transportation greenhouse gas equipment emissions are totally 4189925.60kg carbon dioxide equivalence.

Analyzing greenhouse gas emissions before and after transportation equipment changes, and the following formula. If Q and S\text{average} are fixed, the total load distance is only related to maximum freight volume. Greenhouse gas emissions of the transport equipment is related to diesel consumption of transport equipment in one hundred kilometers.

\[
S_{\text{total}} = Q / L \times S_{\text{average}} \quad (1)
\]

where:
\( S_{\text{total}} \) = total load distance
\( Q \) = total load
\( L \) = maximum freight volume
\( S_{\text{average}} \) = average load distance

The conclusion is that the greater the ratio of diesel consumption of transport equipment in one hundred kilometers to maximum freight volume, the more greenhouse gas emissions.

5. CONCLUSION

- The most greenhouse gas emission in asphalt pavement construction is mixing process
- Compared with warm mix asphalt, heat mix asphalt reduced emissions by 18.2%.
- The main influencing factor of greenhouse gas emission in the transportation process is the ratio between diesel consumption of transport equipment in one hundred kilometers and the maximum freight volume of the transportation equipment.
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