

## Analysis of Exhaust Gas Waste Heat Recovery and Pollution Processing for Z12V190 Diesel Engine

<sup>1,2</sup>Hou Xuejun and <sup>1</sup>Gao Deli

<sup>1</sup>MOE Key Lab of Petroleum Engineering, China University of Petroleum, Beijing 102249, China

<sup>2</sup>College of Petrol Engineering, Chongqing University of Science and Technology, Chongqing 401331, China

**Abstract:** With the increasingly prominent problem regarding rapid economy development and the gradually serious environmental pollution, the waste heat recovery and waste gas pollution processing have received significant attention. Z12V190 diesel engine has high fuel consumption and low thermal efficiency and releases large amounts of exhaust gas and waste heat into the atmosphere, causing serious problems of energy waste and environmental pollution. In this work, the diesel engine exhaust gas components are analysed and the diesel engine exhaust emission rates and exhaust gas waste heat rates are calculated. The calculating results proved the economic feasibility of waste heat recovery from Z12V190 diesel engine exhaust gas. Then, the mainly harmful components are analysed and the corresponding methods of purification and processing about Z12V190 diesel engine exhaust gas pollution discussed. In order to achieve full recovery of waste heat, save energy, purify treatment pollution and ultimate to lay the foundation for waste gas recovery and pollution treatment, the comprehensive process flows of Z12V190 diesel engine exhaust gas pollution processing and waste heat recovery are preliminary designed.

**Key words:** Diesel engine, emissions rates, exhaust gas, pollution processing, process flows, waste heat recovery

### INTRODUCTION

With features of being energy-saving and environment-friendly, the waste heat (WH) recovery and waste gas pollution processing have received significant attention (Khan *et al.*, 2002; Joel and Augusto, 2003; Lee *et al.*, 2010).

Approximately, 30 to 40% of the heat generated in the fuel combustion process is converted into useful mechanical work in contemporary internal combustion engines (Wojciechowski *et al.*, 2010). The remaining heat is emitted to the environment through exhaust gases and engine cooling systems, resulting in an enormous waste of energy and the serious environmental pollution. In the 1980s, developed countries began recycling exhaust gas and WH of internal combustion engines. In 1821, Seebeck had discovered Seebeck Effects. Since 1850, the thermodynamics prompted the constantly development of recycling exhaust gas and WH of automobile internal combustion engine. Pandiyarajan and others have studied experimentally how to recover exhaust gas WH of automobile (Pandiyarajan *et al.*, 2011) and designed a finned tube heat exchanger and a heat storage system (Gunerhan and Hepbasli, 2005). Mostafavi and Agnew have calculated the rate of WH recovery for supercharged

engine exhaust gas (Mostafavi and Agnew, 1997). Aly (1988). have studied the comprehensive applications of exhaust gas recycling and circulating cooling water WH recovery of internal combustion engine (Aly, 1988). Koehler *et al.* (1997) designed a refrigerator system of truck engine exhaust WH (Koehler *et al.*, 1997), with which can replace the conventional compression refrigeration system (Yousef and Najjar, 1996). Horuz experimental research shows that it is feasible to drive refrigeration system with automobile engine exhaust WH (Horuz, 1999). (Manzela *et al.*, 2010) studied ammonia-water absorption refrigeration system with automobile engine exhaust WH drive, and analyzed its economic feasibility. Hilalil and Soylemez (2008) studied the structure of the vehicle exhaust-driven refrigeration system, and conducted optimized calculation of its WH recovery rate and operation economical efficiency. Wu and Schulden (1995) studied improved Carnot-Cycle heat engine driven by high-temperature WH (Wu and Schulden, 1995) and found the relation of a temperature range of high-temperature WH and the maximum specific power. Jung-In (Yoon *et al.*, 2003) studied the exhaust WH driven refrigeration system (Yoon *et al.*, 2003). The highly energy-saving technology with exhaust WH has the remarkable effect in food

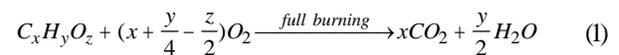
refrigerated-transport and energy saving (Tassou *et al.*, 2010). Bass, Matsubara and others have implemented thermoelectric generators for trucks. BMW/Ford, General Motors, General Electric, and Cummins companies have worked on thermoelectric generator architectures with support from the US Department of Energy (Espinosa *et al.*, 2010). Most cars electronic systems have supplied with power from thermoelectric-generated electricity using diesel engine exhaust gas (DEEG) WH (Hsu *et al.*, 2011). However, all the above efforts have focused mainly on the exhaust gas WH recovery of the automobile internal combustion engines, which is widely used in auto. Researchers rarely see the exhaust gas WH recovery of the Z12V190 diesel engine, which produces large amounts of power and is rarely used in cars.

Since the world's first gasoline engine car appeared in 1888, the auto industry has developed rapidly and the world vehicle production has reached 900 million by 2010 (Kruger, 2001). The vehicle internal combustion engine has been the indispensable power source with the consumption of 30 to 40% of the valuable oil resources at the same time and with the large amount of exhaust gas, which causes serious environment pollution. The 2009 statistics show that only Chinese vehicle emission pollutants has reached 51.434 million tons, of which carbon monoxide (CO) 4018.8 tons, hydrocarbons (HC) 482.2 tons, nitrogen oxides (NO<sub>x</sub>) 583.3 tons and particulate matter (PM) 59.0 million tons (Streets and Waldhoff, 2000). These pollutions are increasing the difficulty of air pollution control, making some areas appear acid rain, haze and photochemical smog and other air pollution frequently, and even it appears the haze more than 200 days every year in some areas. All these problems have directive relations with nitrogen oxides (NO<sub>x</sub>), PM and other pollutants, which are exhausted by motor vehicles. Countries around the world have taken various measures and control strategies and have formulated the more and more stringent emission regulations successively and the U.S is the first to implement vehicle control. As China economic and technological development lags behind, the vehicle emissions control starts late and China develops a variety of automotive pollutant emission standards in 2001, 2004 and 2007 based on the reference to the European emissions regulations to control the motor vehicle exhaust emissions. However, those standards are mainly aimed at the motor vehicle which has a bigger number and the control of exhaust emissions from the Z12V190 diesel

engine with high-power drilling are ignored while its exhaust emissions are directly emitted into the atmosphere which causes tremendous environmental pollution.

Z12V190 diesel engine has high fuel consumption and low thermal efficiency, and releases large amounts of DEEG and WH into the atmosphere, causing energy waste problems. In order to achieve full recovery of WH to save energy and purify treatment mainly harmful components of Z12V190 DEEG to reduce pollution in oil exploration and exploitation, some work must be done. Firstly, the DEEG mainly harmful components will be analyzed. Secondly, the DEEG emissions rate and WH recovery rate will be calculated by employing mass and energy conservation. Finally, the comprehensive process flows of Z12V190 DEEG pollution processing and WH recovery will be preliminary designed. This will have the long-term benefits of promoting the applications of DEEG recycling and WH recovery, improving diesel utilization ratio, saving energy.

**Diesel engine exhaust gas composition analysis:** Each drill crew is normally equipped with 3-6 Z12V190 diesel engines for different well depth and loading conditions. The main performance parameters of Z12V190 diesel engines used in this analysis are as follows: 12 h of power, 1200PS (882 KW); continuous power, 1080PS (794 KW); 209.4 % g/kw ; 0# light diesel fuel composition (C: 0.86, O: 0.004, H: 0.126, etc.). The oxygen can be split and participate in the diesel combustion reactions (Hou *et al.*, 2006). When the oxygen supply is sufficient, only the four main components of CO<sub>2</sub>, O<sub>2</sub>, N<sub>2</sub> and H<sub>2</sub>O are considered:



**Diesel engine exhaust gas waste heat recovery analysis:** During the combustion process of diesel engine, excess O<sub>2</sub> does not participate in the reactions. The O<sub>2</sub> mass percentage (OMP) of DEEG has ranges from 5 to 20%, which leads to different DEEG emission rate and WH recovery rate. Here, the Z12V190 DEEG emission rate and WH recovery rate are analysed for an OMP range of 8 to 19%. According to mass conservation and energy conservation, the main diesel engine exhaust components calculation models establish as follows:

$$[O_2\%] = \frac{[m - x_{kmol} - 4(x_{kmol} + \frac{y_{kmol}}{4} - \frac{z_{kmol}}{2}) - \frac{y_{kmol}}{2}] \times \frac{1}{5} \times 32}{[m - x_{kmol} - 4(x_{kmol} + \frac{y_{kmol}}{4} - \frac{z_{kmol}}{2}) \times 2895 + 4(x_{kmol} + \frac{y_{kmol}}{4} - \frac{z_{kmol}}{2}) \times 28 + x_{kmol} \times 44 + \frac{y_{kmol}}{2} \times 18]} \quad (2)$$

$$m = x_{kmol} + 4\left(x_{kmol} + \frac{y_{kmol}}{4} - \frac{z_{kmol}}{2}\right) + \frac{y_{kmol}}{2} + \frac{\left[4\left(x_{kmol} + \frac{y_{kmol}}{4} - \frac{z_{kmol}}{2}\right) \times 28 \times 44 \times x_{kmol} + 9y_{kmol}\right] \times O_2 \%}{6.4 - 28.95 \times O_2 \%} \quad (3)$$

$$M = \frac{\left[m - x_{kmol} - 4\left(x_{kmol} + \frac{y_{kmol}}{4} - \frac{z_{kmol}}{2}\right) - \frac{y_{kmol}}{4}\right] \times 28.95 + 4\left(x_{kmol} + \frac{y_{kmol}}{4} - \frac{z_{kmol}}{2}\right) \times 28 + x_{kmol} \times 44}{m^t} \quad (4)$$

$$[air]_{kmol} = m - \frac{y_{kmol}}{4} - \frac{z_{kmol}}{2} \quad (5)$$

$$C_{VR} = \alpha_1 + \beta_1.T + \gamma_1.T^2 \quad (6)$$

$$C_p = \frac{4.184C_{VR}}{M_{exhaust}} \quad (7)$$

$$[m]_{coal} = \frac{Q_h}{q} \quad (8)$$

$$Q_h = g_e \cdot C_p \cdot (t_1 - t_2) \cdot [m]_{exhaust} \quad (9)$$

where  $[O_2\%]$  is the OMP of DEEG with water vapour for 1 kg of 0 # light diesel oil;  $m$  is the total mole number of DEEG with water vapour for 1 kg of 0 # light diesel oil, kmol;  $[air]_{mol}$  is the total mole number of combustion air for 1 kg of 0 # light diesel oil, kmol;  $x_{kmol}$  is the C atom mole number of 1 kg of 0 # light diesel oil, kmol;  $y_{kmol}$  is the H atom mole number of 1 kg of 0 # light diesel oil, kmol;  $z_{kmol}$  is the O atom mole number of 1 kg of 0 # light diesel oil, kmol;  $C_{VR}$  is the DEEG Moore specific heat, kcal/(mol.°C);  $\alpha$ ,  $\beta_1$ , and  $\gamma_1$  are constants:  $\alpha_1 = 4.751276526$ ,  $\beta_1 = 1.19900582 \times 10^{-3}$ ,  $\gamma_1 = -1.42321698 \times 10^{-7}$  (Hua and Wang, 1984; Su, 1980);  $t_1$  is the initial temperature in the DEEG WH transfer, °C;  $t_2$  is the termination temperature in the DEEG WH transfer, °C;  $Q$  is the DEEG WH released from the temperature decrease from  $t_1$  to  $t_2$ , KJ;  $g_e$  is the Z12V190 diesel engine fuel consumption, 209.4±5% g/KW.h;  $C_p$  is the DEEG quality specific heat, kJ/(kg•°C).

The calculation results for the DEEG emission rate and WH recovery rate are as shown in Fig. 1 and Fig. 2 in line with the above formulas. For one Z12V190 diesel engine, the increasing intake air volume flow leads to the increasing DEEG OMP and the rapidly increasing DEEG emission rate. In other words, the greater the diesel engine intake air volume flow in a certain range is, which will result in the greater OMP of DEEG, the more fully diesel combustion in diesel engines and the greater DEEG emission rates. The Z12V190 DEEG emission rate is very

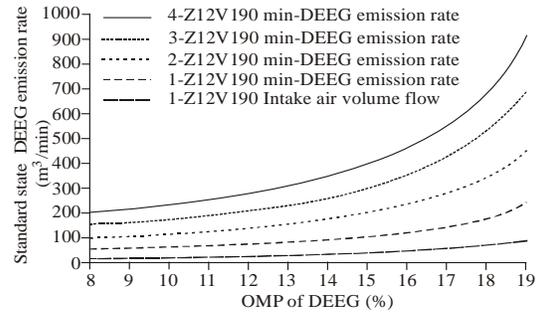


Fig.1: DEEG emission rate curves for different numbers of z12v190s as a function of deeg omp

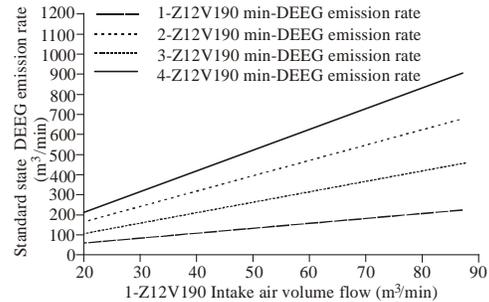


Fig 2: DEEG emission rate curves for different numbers of z12v190s as intake air volume flow

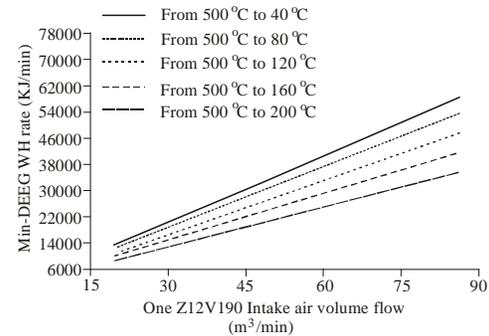


Fig.3: Min-DEEG WH rate curves as a function of intake air volume flow at different temperatures

large and with an increasing number of diesel engine. The min-DEEG emission rate is 49.906 m³/min for one Z12V190 and 199.625 m³/min for 4 Z12V190s. Increases

in the DEEG emission rate lead to a linear increase in the diesel engine intake air volume flow. The Z12V190 DEEG emission rates are very large and rise sharply with an increasing number of diesel engine.

The calculation results for the DEEG WH recovery rate are as shown in Fig. 3. Increases in the DEEG emission rate lead to a linear increase in the DEEG WH rate. An increased difference between the initial temperature and the final temperature leads to an increased DEEG WH recovery rate. For example, the available DEEG WH increases with the increasing temperature difference when the DEEG temperature for one Z12V190 falls from 500 to 200, 160, 120, 80 and 40 . The min-DEEG WH rate is as shown in Fig. 3, and is 36431.31 KJ/min for one Z12V190, 42260.32 KJ/min for 2 Z12V190, 48089.33 KJ/min for 3 Z12V190, 53918.33 KJ/min for 4 Z12V190 and 59747.34 KJ/min for 5 Z12V190. So the possible WH for DEEG is large, and the Z12V190 DEEG WH recovery has great marketing prospects.

**Diesel engine exhaust gas harmful components analysis:** According to emission way, the harmful emissions from a diesel engine can be divided into three

parts: crankcase blowby waste gas, fuel evaporation leakage waste gas and combustion exhaust emissions, although exhaust pollutants are mainly discharged from the exhaust pipe. The component of DEEG is complex, it is a mixture of gases, liquid and solid substances. The gases include  $N_2$ ,  $CO_2$ ,  $CO$ ,  $H_2O$ ,  $NO_x$ ,  $SO_2$ ,  $H_2$ ,  $HC$ , the aldehydes, etc. The liquids include  $H_2SO_4$ ,  $H_2SO_3$ ,  $HNO_3$ , etc. Solids include dry soot, lead oxide, carbide, metal compounds, sulfate, solid hydrocarbons, etc (Er, 2002; Biswas *et al.*, 2008; Musthafa *et al.*, 2011). Since  $N_2$ ,  $O_2$ ,  $H_2$ ,  $CO_2$  and other ingredients are harmless gas. The PM and many of them, such as  $HC$ ,  $CO$ ,  $NO_x$ ,  $SO_2$ , etc., are toxic and great harms to human health (shown the formula (10)) (Zhu *et al.*, 2011). The  $SO_2$  content is less and the concentration of  $HC$ ,  $CO$ ,  $NO_x$  is related to an excess air ratio. The concentration of  $CO$  in the oxygen-rich zone is very low, but increased rapidly in the anoxic zone.  $NO_x$  reached the maximum when the excess air ratio is 1.1, and declined rapidly in both oxygen-rich zone and anoxic zone. When the excess air ratio is 1.1 to 1.25, the  $HC$  is at the least, the major pollutants are PM and  $NO_x$ . Therefore, development of DEEG purifying and pollution processing technology mainly focus on the two pollutants of PM and  $NO_x$ .

$$DEEG \text{ Components} = \left[ \frac{\text{non-toxic}}{CO_2 + H_2O + N_2 + H_2 + \frac{O^2}{5\% \sim 20\%}} \right] + \left[ \frac{\text{toxic}}{\frac{CO}{< 0.01\%} + \frac{HC}{< 0.05\%} + \frac{NO_x}{< 1\%} + \frac{SO_2}{0.01 \sim \%0.027\%} + \frac{PM}{< 1\%}} \right] \quad (10)$$

PM is composed mainly of the solid soot, soluble organic matter and sulfate, of which the soot is the major part of particles. The soot is formed in the condition of high-temperature and hypoxia, and its formation quantity reaches the highest level when the temperature is 2100-2400K. The diesel engine is oxygen-enriched combustion, but the soot produces due to the local hypoxia caused by the mixture's non-uniform. The specific process of formation can be divided into three stages: First, the fuel molecules at high-temperature pyrolyze to form the core of soot. Then, the soot particle unit is formed through the two processes of surface growth and condensation, but the reaction rate begins to slow with the further reaction fierce. Finally, each soot particle unit accumulates together and forms the soot. The soot particle is relatively small size and can suspend in the atmosphere for a long time, increasing the chemical change opportunities of particle's touching the body between the soot particle and other matters in the atmosphere. The soot particle cannot only reduce the visibility of the atmosphere, but also is easy to be inhaled into the lungs and aggravates respiratory diseases. Meanwhile, the soluble organic in

the soot also has carcinogens. Therefore, the hazards that the particulate emissions have on atmosphere and human should also arouse our attention.

$NO_x$  is to be called as the combustion product  $NO$  and  $NO_2$ , the vast majority of which is  $NO$  (about 95%), usually we use  $NO_x$  to express the total amount of the two components (Koebe *et al.*, 2000).  $NO$  is a colorless gas, it has great harm to the atmosphere, plant growth and even the human body health. The high density of  $NO$  can cause problems to the central nervous, and it can be rapidly oxidized with  $O_3$  to  $NO_2$  in the atmosphere, then destroy the atmosphere.  $NO_2$  is maroon harmful gases with special exciting odour, if it is absorbed into the body and combined with moisture, it then generates nitric acid, which can strongly stimulate the heart, lungs, hematopoietic organization of a body.

**Diesel engine exhaust gas recycling:**

**Diesel engine exhaust gas waste heat recovery:** The maximum outlet temperature for Z12V190 DEEG is about 600 (Conklin and Szybist, 2010). Based on the calculated values on DEEG emission rate, suppose DEEG WH

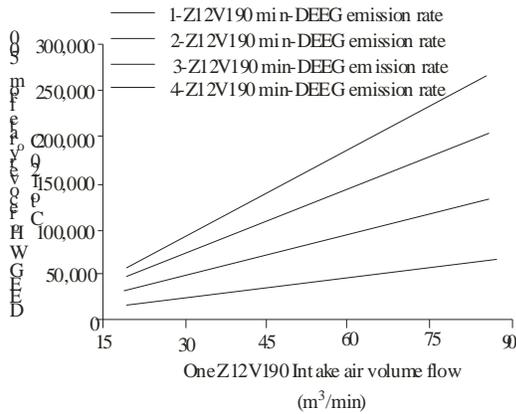


Fig.4: DEEG WH Recovery Rate Curves As a Function of Intake Air Volume Rate From 450;æ To 120;æ

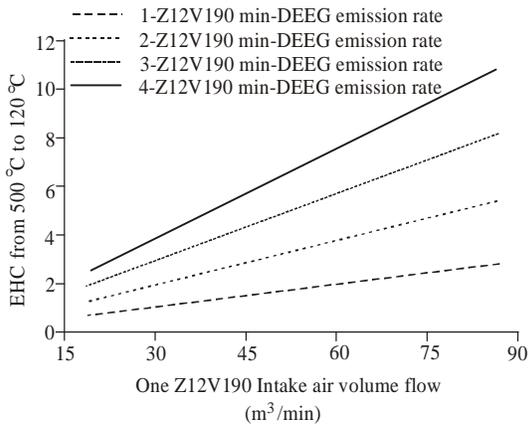


Fig.5: EHC Curves As a Function of Intake Air Volume Rate From 450;æ To 120;æ

recovery systems, such as heat pipe boilers, TEGs, heat energy store exchangers, and modern air cooling and heating systems, can use 70% of the DEEG WH from 500 to 120 . According to the usual thermal efficiency of the DEEG WH recovery systems, the calculation results for the DEEG WH recovery rates are as shown in Fig. 4 and 5. When the temperature of the Z12V190 DEEG is decreased from 500 to 120 , the value of the available DEEG WH transferred by heat exchange equipments increases proportionally with not only the number of diesel engines, but also the intake air volume flow (Fig. 4). According to the normal anthracite calorific value, the minimum quantity of equivalent heat coal (EHC) and the value of the available DEEG WH transferred by heat exchange equipment are both large when the temperature of the Z12V190 DEEG is decreased from 450 to 120 . The minimum EHC is 0.61 ton/ (24 h) for one Z12V190. The EHC is shown in Fig. 5. So the Z12V190 DEEG WH recovery has great marketing prospects.

**Diesel engine exhaust gas pollution processing:** Since the major pollutants of the DEEG are PM and NO<sub>x</sub>, the development of DEEG purification technology is mainly for the above two pollutants. The DEEG purification device is various and can be divided into two major kinds: dry reaction purification device and wet scrubbing purification device.

Dry reaction purification device can be use to treat PM pollution, such as particle trapper, electrostatic absorption and oxidation catalytic converter. The methods used to deal with NO<sub>x</sub> include Selective Non Catalyst Reduction (SNCR), Selective Catalytic Reduction (SCR), Non-Selective Catalytic Reduction (NSCR), carbon fiber to reduce NO, etc (Javed *et al.*, 2007). Based on the characteristics of drilling diesel engine Z12V190 and the large quantity of DEEG, we can separately use particle trapper and electrostatic absorption device to cleansing PM. The particle trapper uses the mechanical filtration principles of collision and intercepts to achieve the purpose of trapping soot. The filter materials include ceramic honeycomb filter materials, woven ceramic fiber, metal honeycomb and metal fiber braid, etc. (Hawker, 1995). For the electrostatic absorption device, the nearly 70 to 80% (mass percentage) of soot particles under large loading were the charge state, each charged particle has 1-5 positive or negative charges, the whole is neutral, an additional electric field can be used to form the electrostatic adsorption of soot particles with the removal efficiency up to 50-75%. Meanwhile, it convenient to use the SCR of NO<sub>x</sub> treatment with in the wild well site. The reducing agents of ammonia and urea are sprayed into the DEEG, and join the corresponding catalyst V<sub>2</sub>O<sub>5</sub>, WO<sub>3</sub>, V<sub>2</sub>O<sub>5</sub>/MoO<sub>3</sub>, Fe<sub>2</sub>O<sub>3</sub>, Cu-ASM-5, etc (Mul *et al.*, 1995; Petunchi and Hall, 1993).

Wet scrubbing is one method based on solution absorb. It can remove the harmful pollutants from DEEG completely and reduce exhaust temperature. At present, some of the diesel camions and the diesels used underground abroad are generally equipped with a wet scrubbing device, such as underground scrapers in Germany, France and Volvo BM861-type dump diesel cars in Sweden (Schmidt, 1995). Considering the large quantity of waste gas, we can use pure water as absorbing liquid to remove excitant gas (such as aldehyde), some HC with oxygen and high boiling point (such as aldehyde, grease, alcohol, acid) and a little SO<sub>2</sub>. Because CO HC NO and soot have low solubility in water. Some sorbent can be added into water so as to enhance the absorbing capacity for harmful gas, which is poorly soluble in water. At the same time, through the atomization method, the small carbon soot and dust particles can be combined with liquid to increase the diameter, get them easily removed. Efficient absorbent, which can change the hydrophilicity of soot, can be added into scrubbing liquid to increase the rate of removal of soot.

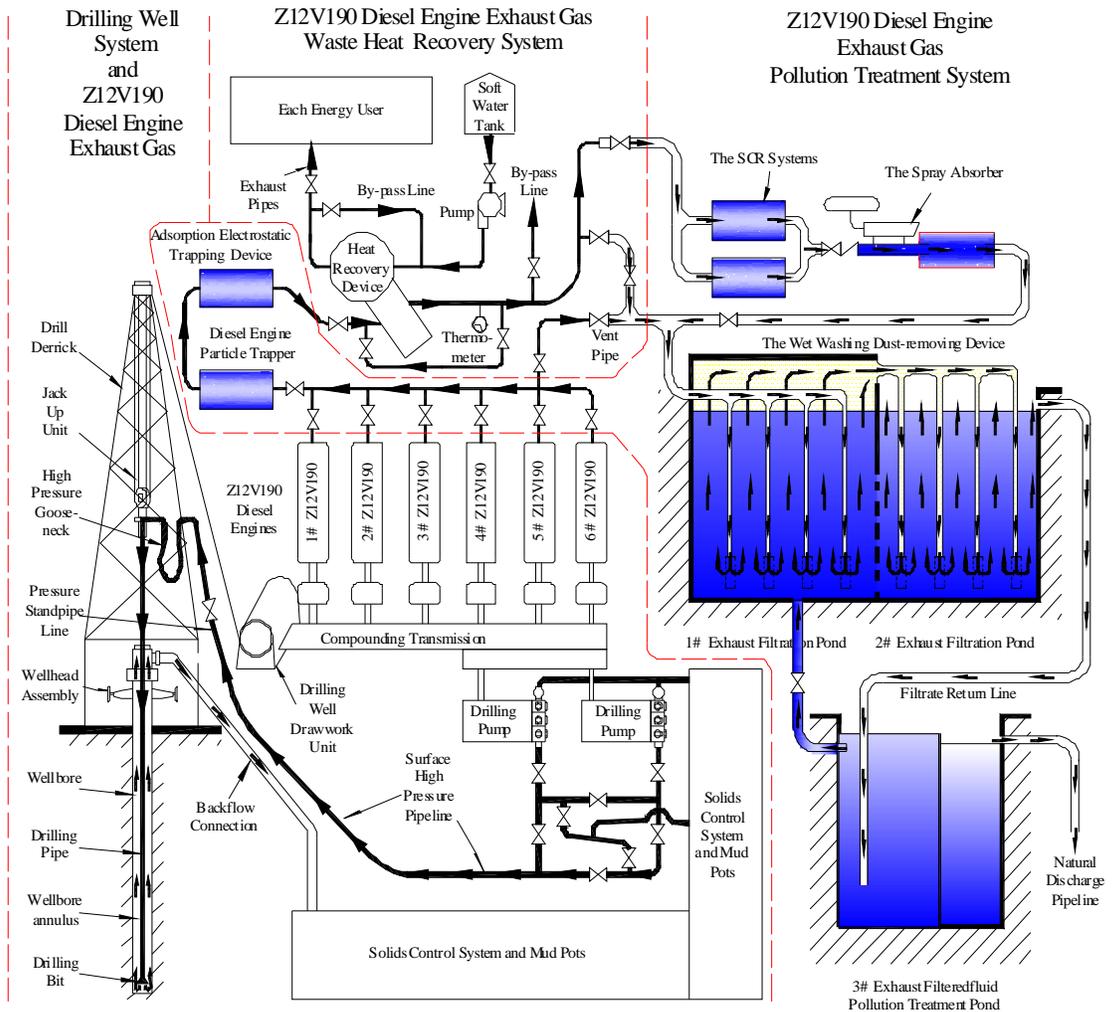


Fig. 6: Flow diagram of z12v190 diesel engine exhaust gas comprehensive utilization

**Process flows of Z12V190 diesel engine exhaust gas comprehensive utilization:** Based on the character of conventional drilling, an integrated design of WH recovery and pollution processing is made for Z12V190 DEEG. The integrated process flows are preliminary designed as Fig. 6. The temperature of DEEG is very high when it gets out from working diesel engine. First, it is transported into the particle trapper through the pipeline and most soot can be removed there. Second, 50-75% of the other soot with electric charge will be removed through electrostatic absorption under the additional electric fields when the DEEG passes the electrostatic absorption trapper. Then it is transported into a WH recovery device such as hot pipe boiler, thermal power generation and heat energy storage equipment (Fig. 6 is based on hot pipe boiler.) and is transformed into

available energy for users in the drilling crew. The DEEG can give out heat constantly through the heat energy conversion devices until the temperature dropped to drilling license temperature. The cooled DEEG is transported into NO<sub>x</sub> Selective Catalytic Reduction (SCR), and the NO<sub>x</sub> is reduced and become N<sub>2</sub>. When the gas passes through the spray absorption equipment, it gets atomization treatment and is added by some additive treating agent. The most toxic substance such as HC CO NO<sub>x</sub> SO<sub>2</sub> becomes small droplet from gas or dust when combined with spray liquid treatment agent. So it is easy to get rid of them. Most of the toxic substance can be cleared away in the 1 # and 2 # filtering ponds of a wet scrubber system. Then we can get clean gas and discharge it into the atmosphere. Meanwhile, the filtered fluid in the 1 and 2 # filtering ponds can be processed in the 3 # waste

gas and filtrate treatment system and become liquid without pollution and can be discharged into the nature. So, after these processes, there is no pollution caused by DEEG. By this method, we can make full use of Z12V190 DEEG, improve the utilization rate of diesel, save the energy and reduce the pollution caused by waste gas.

### CONCLUSION

- It has analyzed the Z12V190 DEEG emission rate and WH rates. The results showed as follows: the DEEG WH recovery rates increase with increasing DEEG emission rates and are very large. Rational WH recovery for the Z12V190 DEEG is feasible and has a good development prospect.
- It has analyzed the Z12V190 DEEG components, its main harmful substances and the corresponding processing methods. The analysis results showed as follows: The pollution processing of the main harmful components is necessary for the Z12V190 DEEG, and the corresponding processing methods are feasible.
- It has set up the process flows of WH recovery and pollution processing for the Z12V190 DEEG, and established a theoretical foundation for the Z12V190 DEEG WH recovery and pollution processing.

### ACKNOWLEDGMENT

The authors are grateful for the financial support from the national projects (Grant No.: 2011ZX05009-005 and 2010CB226703).

### REFERENCES

- Aly, S.E., 1988. Diesel engine waste-heat power cycle. *Appl. Energ.*, 29: 179-189.
- Biswas, S., S.H. Hua, V. Verma, J.D. Herner, W.H. Robertson and A. Alberto, 2008. Physical properties of particulate matter (PM) from late model heavy-duty diesel vehicles operating with advanced PM and NO<sub>x</sub> emission control technologies. *Atmos. Environ.*, 42: 5622-5634.
- Conklin, J.C. and J.P. Szybist, 2010. A highly efficient six-stroke internal combustion engine cycle with water injection for in-cylinder exhaust heat recovery. *Energy*, 35: 1658-1664.
- Er, I.D., 2002. Overview of NO<sub>x</sub> emission controls in marine diesel engines. *Energ. Source*, 24: 319-327.
- Espinosa, N., M. Lazard, L. Aixala and H. Scherrer, 2010. Modeling a thermoelectric generator applied to diesel engine automotive heat recovery. *J. Electron. Mater.*, 39: 1446-1455.
- Gunerhan, H. and A. Hepbasli, 2005. Utilization of basalt stone as a sensible heat storage material. *Energ. Source*, 27: 1357-1366.
- Hawker, B.N., 1995. Diesel emission control technology. System containing Platinum catalyst and filter unit removes Particulate from diesel exhaust. *Platinum Met. Rev.*, 39: 2-8.
- Hilalil, I. and M.S. Soylemez, 2008. On the optimum sizing of exhaust gas-driven automotive absorption cooling systems. *Int. J. Energ. Res.*, 32: 655-660.
- Horuz, I., 1999. Vapor absorption refrigeration in road transport vehicles. *J. Energ. Eng.*, 125(2): 48-58.
- Hou, X.J., Z.J. Zhu, M.H. Pang and H.J. Lv, 2006. Probability analysis of heat pipes boilers of diesel engine for drilling well. *Mecha. Res. And Appl.*, 19: 41-43.
- Hsu, C.T., G.Y. Huang, H.S. Chu, B. Yu and D.J. Yao, 2011. Experiments and simulations on low-temperature waste heat harvesting system by thermoelectric power generators. *Appl. Energ.*, 88: 1291-1297.
- Hua, J.Y. and Z.Y. Wang, 1984. Calculation and application of combustion heat release rate in high speed diesel engine. *Trans. Csice*, 2: 103-123.
- Javed, M.T., N. Irfan and B.M. Gibbs, 2007. Control of combustion-generated nitrogen oxides by selective non-catalytic reduction. *J. Environ. Manage.*, 83: 251-289.
- Joel, H.S. and S.C. Augusto, 2003. Trigeneration: An alternative for energy saving. *Appl. Energ.*, 76: 219-227.
- Khan, K.H., M.G. Rasul and M.M.K. Khan, 2002. Energy conservation in buildings: Cogeneration and cogeneration coupled with thermal-energy storage. *Appl. Energ.*, 77: 15-34.
- Koehler, J., W.J. Tegethoff, D. Westphalen and M. Sonnekalb, 1997. Absorption refrigeration system for mobile applications utilizing exhaust gases. *Heat Mass Transfer*, 32: 333-340.
- Kruger, P., 2001. Electric power requirement for large-scale production of hydrogen fuel for the world vehicle fleet. *Int. J. Hydrogen Energ.*, 26: 1137-1147.
- Koebe, M., M. Elsener and M. Kleenlann, 2000. Urea-SCR: A promising technique to reduce NO<sub>x</sub> emissions from automotive diesel engines. *Catal. Today*, 59: 335-345.
- Lee, H.D., J.S. Lee and J.S. Park, 2010. Effects of secondary combustion on efficiencies and emission reduction in the diesel engine exhaust heat recovery system. *Appl. Energ.*, 87: 1716-1721.
- Manzela, A.A., S.M. Hanriot, L. Cabezas-G ez and J.R. Sodr 2010. Using engine exhaust gas as energy source for an absorption refrigeration system. *Appl. Energ.*, 87: 1141-1148.

- Mostafavi, M. and B. Agnew, 1997. Thermodynamic analysis of Combined diesel engine and absorption refrigeration unit-naturally aspirated diesel engine. *Appl. Therm. Eng.*, 17: 471-478.
- Mul, G., J.P.A. Neeft and F. Kapteijn, 1995. Soot oxidation catalyzed by a Cu/K/Mo/Cl catalyst: Evaluation of the chemistry and performance of the catalyst. *Appl. Catal. B: Environ.*, 6: 339-352.
- Musthafa, M.M., S.P. Sivapirakasam and M. Udayakumar, 2011. Comparative studies on fly ash coated low heat rejection diesel engine on performance and emission characteristics fueled by rice bran and pongamia methyl ester and their blend with diesel. *Energy*, 36: 2343-2351.
- Pandiyarajan, V., M. Chinna Pandian, E. Malan, R. Velraj and R.V. Seeniraj, 2011. Experimental investigation on heat recovery from diesel engine exhaust using finned shell and tube heat exchanger and thermal storage system. *Appl. Energ.*, 88: 77-87.
- Petunchi, J.O. and W.K. Hall, 1993. On the role of nitrogen dioxide in the mechanism of the selective reduction of NO<sub>x</sub> over Cu-ZSM-5 zeolite. *Appl. Catal. B: Environ.*, 2: 17-26.
- Schmidt, R.M., 1995. Diesel wet exhaust purifying method. DE4, 327469.
- Streets, D.G. and S.T. Waldhoff, 2000. Present and future emissions of air pollutants in China: SO<sub>2</sub>, NO<sub>x</sub> and CO. *Atmospheric Environ.*, 34: 363-374.
- Su, Y.Q., 1980. Specific heat experiential formula for diesel engine combustion products. *Chinese Internal Combustion Eng.*, 1: 74-76: 86.
- Tassou, S.A., J.S. Lewis, Y.T. Ge, A. Hadawey and I. Chaer, 2010. A review of emerging technologies for food refrigeration applications. *Appl. Therm. Eng.*, 30: 263-276.
- Wojciechowski, K.T., M. Schmidt, R. Zybala, J. Merksiz, P. Fuc and P. Lijewski, 2010. Comparison of waste heat recovery from the exhaust of a spark ignition and a diesel engine. *J. Electron. Mater.*, 39: 2034-2038.
- Wu, C. and W.H. Schulden, 1995. Maximum obtainable specific power of high-temperature waste heat engines. *Heat Recov. Syst.*, 15: 13-17.
- Yoon, J.I., K.H. Choi, C.G. Moon, Y.J. Kim and O.K. Kwon, 2003. A study on the advanced performance of an absorption heater/chiller with a solution preheater using waste gas. *Appl. Therm. Eng.*, 23: 757-767.
- Yousef, S. and H. Najjar, 1996. Enhancement of performance of gas turbing engines by inlet air cooling and cogenration system. *Appl. Therm. Eng.*, 16: 163-173.
- Zhu, R.J., C.S. Cheung, Z.H. Huang and X.B. Wang, 2011. Experimental investigation on particulate emissions of a direct injection diesel engine fueled with diesel-diesel adipate blends. *J. Aerosol Sci.*, 42: 264-276.