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Studies on exhaust gas recycling and waste heat recovery for the Z12V190 diesel engine

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ABSTRACT

The Z12V190 diesel engine has high fuel consumption and low thermal efficiency, and releases large amounts of diesel exhaust gas and waste heat into the atmosphere. This causes huge resource as well as energy waste. In order to protect the environment, save energy, and also to solve these problems about exhaust gas recycling and waste heat recovery, the Z12V190 diesel engine exhaust emission rate and minimum gas injection rate for gas underbalanced drilling are calculated and compared with the deduced formulas. The critical point pressure range of different diameter drill pipe has been deduced in the same diameter well, which proved the application feasibility of the Z12V190 diesel engine exhaust gas underbalanced drilling. Meanwhile, the waste heat recovery rate has been calculated and proved the economic feasibility of the Z12V190 diesel engine exhaust gas waste heat recovery. The process flows are designed for the Z12V190 diesel engine exhaust gas underbalanced drilling well and its waste heat recovery. The Z12V190 diesel engine exhaust gas will be recycled to reduce pollution, and its waste heat recovery be used for saving energy resources.

Keywords: Diesel engine; exhaust gas; underbalanced drilling; recycling; waste heat recovery.

INTRODUCTION

Between 1900 and 1955 the average rate of global energy use rose from about 1 TW to 2 TW. Between 1955 and 1999 energy use increased from 2 TW to about 12 TW, and to 2006 a further 16% growth in primary energy use was recorded world-wide (Reay, 2008). With the increasingly rapid economic development and a relative shortage of the energy supply, the diesel engine exhaust gas (DEEG) recycling and waste heat (WH) recovery has received significant attention.

The technology theory research and experimental work on DEEG underbalanced drilling (UBD) has been done at the southwestern Sichuan Basin and the Southwest Petroleum Institute in China. The practical application of DEEG UBD has achieved good economic results in Sichuan oil and gas fields (Wei *et al*., 2008). However, the DEEG UBD is facing some problems: whether the DEEG emission rate meets the minimum gas injection rate (min-GIR) or not in wells of different depth, and also whether O2 mass percentage (OMP) meets the safety requirements of underground blasting or not.

In the 1980s, developed countries began recycling exhaust gas and WH of internal combustion engines. Since 1850, the thermodynamics prompted the constantly development of recycling exhaust gas and WH of the automobile internal combustion engine. Mostafavi *et al*. (1998) and Mostafavi & Agnewt (1997) have calculated the rate of WH recovery for supercharged engine exhaust gas. Aly (1992) have studied the comprehensive applications of exhaust gas recycling and circulating cooling water WH recovery of the internal combustion engine. Koehler *et al*. (1997) designed a refrigerator system of truck engine exhaust WH, which can replace the conventional compression refrigeration system (Najjar, 1996; Turnpenny *et al*., 2001). Horuz & Callander (2004) experimental research shows that it is feasible to drive refrigeration system with automobile engine exhaust WH. Wu & Schulden (1995) and Wu (1996) studied improved Carnot-Cycle heat engine driven by high-temperature WH, and found the relation of a temperature range of high-temperature and the maximum specific power. Yoon *et al*. (2003) studied the exhaust WH driven refrigeration system. The highly energy-saving technology with exhaust WH has the remarkable effect in food refrigerated-transport and energy saving (Tassou *et al*., 2009; Tassou *et al*., 2010). Bass *et al*. (1994), Matsubara (2002) have implemented thermoelectric generators for trucks. Electronic systems of most car have been supplied with power from thermoelectric-generated electricity, using DEEG WH (Najjar, 1996). 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 industry. 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.

The Z12V190 diesel engine has released large amounts of DEEG and WH into the atmosphere, causing energy waste problems. Based on the environmental (Barakat *et al*., 2014; Ahmed & Al-Dousari, 2013) concern, the DEEG components are analyzed, and the DEEG emissions rate and WH recovery rate are calculated respectively. Combined with min-GIR of gas UBD, the feasibility of exhaust gas UBD would be proved for the Z12V190 diesel engine. Meanwhile, the feasibility of DEEG recovery would be proven, and the process flows of the Z12V190 DEEG UBD and WH recovery would be designed. These can make up for the deficiency in current research on Z12V190 DEEG recycling and WH recovery in oil exploration and exploitation.

DIESEL ENGINE EXHAUST GAS COMPOSITION ANALYSIS

The relative performance parameters of Z12V190 diesel engines are as follows: 12 hours of power, 1200PS (882 KW); continuous power, 1080PS (794 KW); 209.4 ± 5% g/kw·h; 0# light diesel fuel composition (C: 0.86, O: 0.004, H: 0.126, etc.). When the oxygen supply is sufficient, only the four main components of CO2, O2, N2 and H2O are considered by Hou *et al*. (2006).

$$C_xH_yO_z + (x + \frac{y}{4} - \frac{z}{2})O_2 \xrightarrow{\text{full burning}} xCO_2 + \frac{y}{2}H_2O \quad (1)$$

Diesel engine exhaust gas emissions rate analysis

Here, the Z12V190 DEEG emission rate and WH recovery rate are analysed for an OMP range of 8 to 19 %. The main DEEG components' calculation models (Hou & Gao, 2011) are established as follows:

$$[O_2\%] = \frac{[m - x_{kmol} - 4(x_{kmol} + \frac{y_{kmol}}{4} - \frac{z_{kmol}}{2}) - \frac{y_{kmol}}{2}] \times \frac{1}{5} \times 32}{[m - x_{kmol} - 4(x_{kmol} + \frac{y_{kmol}}{4} - \frac{z_{kmol}}{2}) - \frac{y_{kmol}}{2}] \times 28.95 + 4(x_{kmol} + \frac{y_{kmol}}{4} - \frac{z_{kmol}}{2}) \times 28 + x_{kmol} \times 44 + \frac{y_{kmol}}{2} \times 18} \quad (2)$$

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

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

where $[O_2\%]$ is the OMP of DEEG; m is the total mole number of DEEG with water vapour for 1 kg of 0# light diesel oil, kmol; $M_{exhaust}$ is the average molecular weight of DEEG without water vapour, kg/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.

According to the above models, the calculated results show that each curve implies that the min-DEEG emission rate is large and increases rapidly with the increase of the OMP of DEEG (Table 1 and Fig.1).

Table 1. One Z12V190 DEEG WH Recovery Rate at Different OMP of DEEG

OMP Of DEEG	One Z12V190 Intake Air Volume Flow	One Z12V190 DEEG Emission Rate	The available Z12V190 DEEG WH increases with increasing temperature difference when Z12V190 DEEG temperature falls from t1 to t2. (KJ/min)				
			The initial temperature t1 is 500°C				
			The final temperature t2 is shown below				
(%)	m3/min	m3/min	200°C	160°C	120°C	80°C	40°C
8	18.6	49.9	8116.3	9414.9	10713.6	12012.2	13310.8
9	20.1	53.7	8726.5	10122.8	11519.0	12915.3	14311.5
10	21.8	58.2	9437.5	10947.5	12457.5	13967.5	15477.5
11	23.9	63.4	10276.6	11920.8	13565.0	15209.3	16853.5
12	26.3	69.7	11281.6	13086.7	14891.7	16696.8	18501.8
13	29.3	77.3	12507.4	14508.5	16509.7	18510.9	20512.1
14	33.0	86.9	14035.5	16281.2	18526.9	20772.6	23018.3
15	37.7	99.1	15993.7	18552.7	21111.7	23670.7	26229.7
16	44.0	115.3	18593.2	21568.1	24543.1	27518.0	30492.9
17	52.7	137.9	22210.7	25764.4	29318.1	32871.8	36425.6
18	65.7	171.5	27589.8	32004.1	36418.5	40832.9	45247.2
19	87.1	226.6	36431.3	42260.3	48089.3	53918.3	59747.3

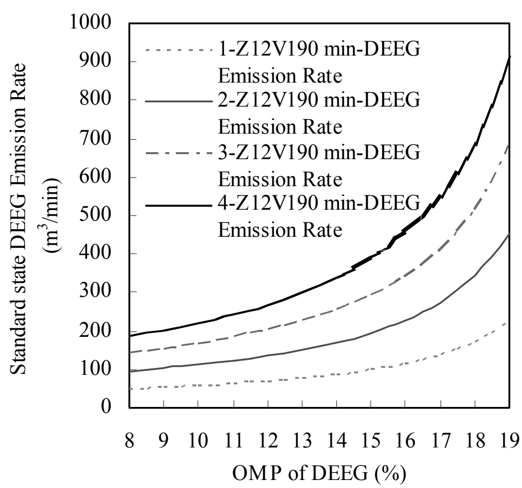

Fig.1. DEEG Emission Rate Curves for Different Numbers of Z12V190s as a Function of DEEG OMP

Diesel engine exhaust gas waste heat recovery analysis

According to the conservation of energy, the calculation models of the DEEG WH recovery rate (Hou & Gao, 2012) and its equivalent coal quantity are as follows:

$$C_{VR} = \alpha_1 + \beta_1 \cdot T + \gamma_1 \cdot T^2 \tag{5}$$

$$C_P = \frac{4.184 C_{VR}}{\overline{M}_{exhaust}} \tag{6}$$

$$[m]_{coal} = \frac{Q_h}{q} = \frac{g_e \cdot C_P \cdot (t_1 - t_2) \cdot [m]_{exhaust}}{q} \tag{7}$$

$$Q_h = g_e \cdot C_P \cdot (t_1 - t_2) \cdot [m]_{exhaust} \tag{8}$$

where C_R is the DEEG Moore specific heat, kcal/(mol·°C); α_1, β_1 and γ_1 are constants: $\alpha_1 = 4.751276526$, $\beta_1 = 1.19900582 \times 10^{-3}$, $\gamma_1 = -1.42321698 \times 10^{-7}$ (Hua & Wang, 1984; Su, 1980); t_1 is the DEEG initial temperature in WH transfer, °C; t_2 is the DEEG final temperature in WH transfer, °C; Q_h is the DEEG WH released from t_1 to t_2, KJ; g_e is the Z12V190 fuel consumption, 209.4±5% g/(KW·h); C_P is the DEEG quality specific heat, kJ/(kg·°C).

The calculation results of the minimum DEEG WH recovery rate for Z12V190 are as shown in Table 1. Increases in the DEEG emission rate lead to a linear increase in the DEEG WH rate. An increased difference between DEEG initial temperature and DEEG final temperature leads to an increased DEEG WH recovery rate.

DIESEL ENGINE EXHAUST GAS RECYCLING

Diesel engine exhaust gas underbalanced drilling

For DEEG UBD, some formulas to modify min-GIR are derived by the analysis of DEEG density at the critical point (CP) on the basis of the minimum kinetic energy method (Tabatabaei *et al*., 2008; Guo & Ghalambor, 2006; Johnson, 1991; Carlos & Chi, 1982; Angel, 1957), such as formula (9) and (10). The minimum gas velocity will be calculated by the following formulas (11) and (12). All this formulas are shown as follows.

$$\rho_{01} = \frac{p}{RT} \frac{\left[m - x_{kmol} - 4\left(x_{kmol} + \frac{y_{kmol}}{4} - \frac{z_{kmol}}{2} \right) - \frac{y_{kmol}}{2} \right] \times 28.95 + 4\left(x_{kmol} + \frac{y_{kmol}}{4} - \frac{z_{kmol}}{2} \right) \times 28 + x_{kmol} \times 44}{m'} \tag{9}$$

$$v_g = \sqrt{\frac{\rho_{g0} \times v_{g0}^2 \times p_{01} \times T_g}{p_g \times T_{01} \times \rho_{01}}} \tag{10}$$

$$Q_g = \frac{\pi}{4} v_g \left(D_h^2 - D_{p0}^2\right) \tag{11}$$

$$Q_{g0} = Q_g \frac{pT_0}{p_0 T} \tag{12}$$

where ρ_{g0} is the gas density at standard atmospheric conditions, kg/m^3; ρ_{01} is the gas density at pressure p_{01} and temperature T_{01}, kg/m^3; Qg is the min-GIR at standard atmospheric conditions, m^3/s; Qg0 is the min-GIR at pressure p_{01} and temperature , T_{01} m^3/s; Dh is the wellbore diameter, mm; Dp0 is the outside diameter of DP, mm; M is DEEG molar mass, kg/kmol; R is the general gas constant.

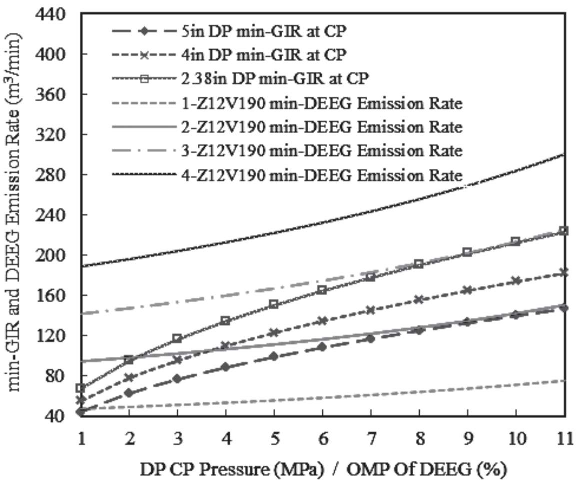

Fig.2. Curves for DEER and CP min-GIR at Different Pressure and OMP

The CP pressure, which determines the min-GIR, is different according to the CP depth. The results are as shown in Figure 2. The DEEG UBD is not only suitable for low-pressure shallow wells, but also for low-pressure deep wells. As the well becomes deeper or the annular cross-sectional area becomes smaller, CP pressure will increase. On the contrary, the CP pressure will be lesser. According to the analysis of calculation results, the DEEG emission rate determines the CP pressure range. The CP pressure range is as shown in Figure 2.

Diesel engine exhaust gas waste heat recovery

The Z12V190 DEEG outlet temperature is about 500^{o}C (Conklin & Szybist, 2010). Suppose DEEG WH recovery systems can use 70% of the DEEG WH from 500^{o}C to 120^{o}C, the DEEG WH rates are as shown in Fig.3 and Table 1, the available DEEG WH rate is large and increases proportionally with the number of diesel engines. The possible cost savings of DEEG WH recovery is large, and the Z12V190 DEEG WH recovery has great marketing prospects.

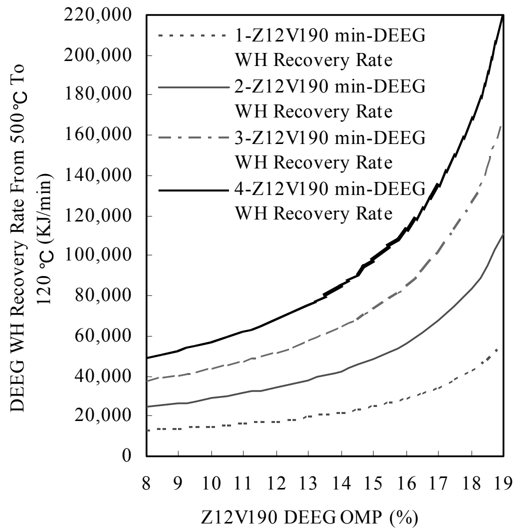

Fig.3. DEEG WH Recovery Rate Curves for DEEG Emission Rate from 500°C to 120°C

DIESEL ENGINE EXHAUST GAS COMPREHENSIVE APPLICATION

The schematic flowchart of comprehensive applications on DEEG recycling is as shown in Figure 4. The DEEG arrives at the WH recovery systems by the pipeline. The WH recovery systems (Reay, 2002; Reay *et al*., 2008) recover DEEG WH into available energy and send it to the drilling crew users. The DEEG releases WH constantly until the DEEG temperature drops to the drill well permit temperature. Then the DEEG goes through the air compressors, supercharger and other equipments to achieve the high-pressure requirements of gas UBD.

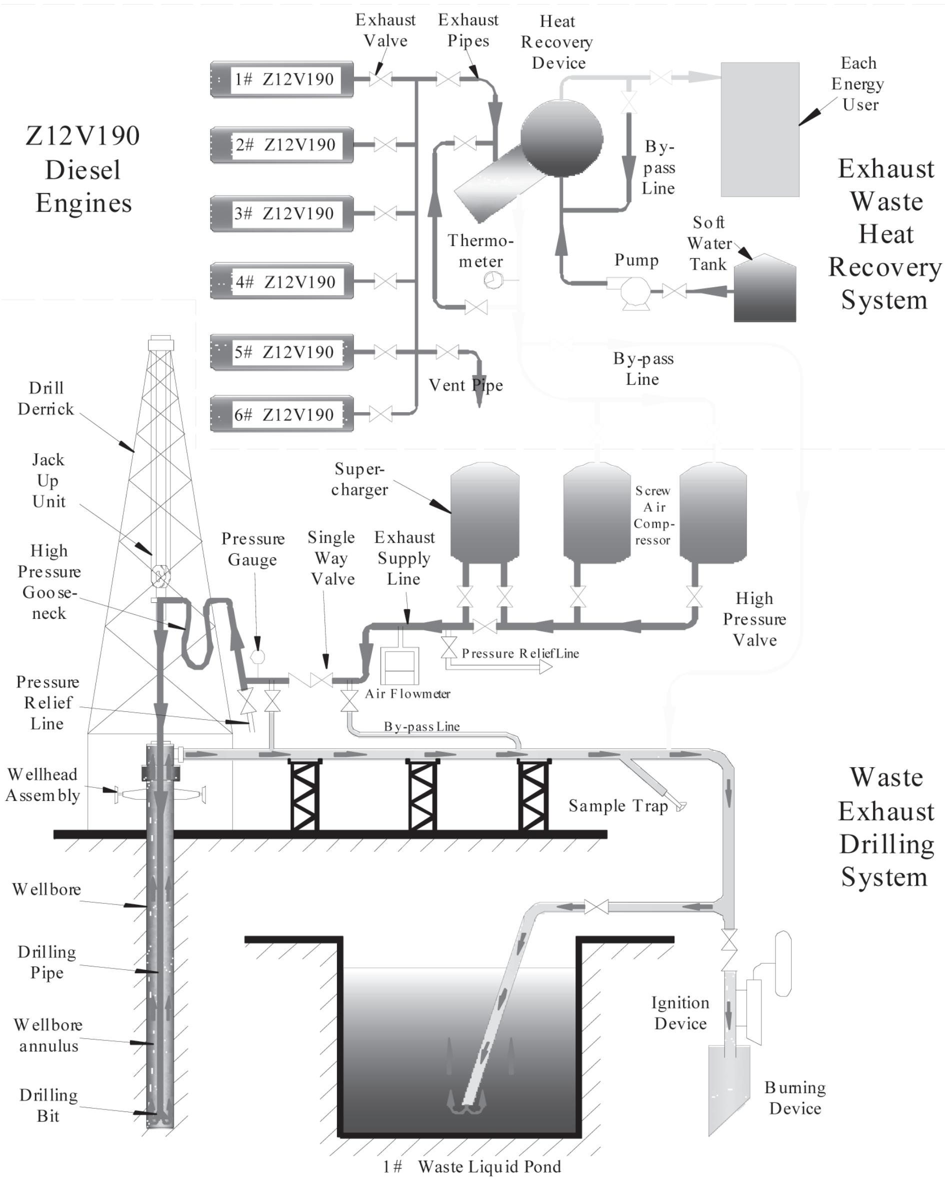

Fig.4. Schematic Flowchart of Comprehensive Applications on DEEG Recycling and WH Recovery

The high pressure DEEG passes through the standpipe, drilling hose and DP water eye, etc., to arrive at the bottom hole to clean and carry the cuttings back to the ground along the DP annular space. Finally, the DEEG goes through the dust filtration equipments and debris waste reservoirs to remove the dust and cuttings, and releases it in to the atmosphere.

CONCLUSIONS

(1) The DEEG UBD is feasible for low-pressure oil and gas fields. It has given CP pressure ranges of DEEG UBD corresponding to different DEEG emission rates with different diameter DPs in a same diameter well.

(2) The DEEG WH rate increases with an increasing DEEG emission rate and is very large. Rational DEEG WH recovery is feasible and has a good economic development prospect.

(3) The process flows of DEEG UBD and WH recovery for Z12V190 diesel engine has been set up.

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NOMENCLATURE

DEEG	diesel engine exhaust gas
WH	waste heat
UBD	underbalanced drilling;
min-GIR	minimum gas injection rate
OMP	O_2 mass percentage or oxygen mass percentage
DP	drill pipe or drill pipes
CP	critical point

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دراسات عن إعادة تدوير غاز العادم واستغلال الحرارة المفقودة لمحرك الديزل Z12V190

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خلاصة

محرك الديزل Z45V190 يستهلك كميات كبيرة من الوقود وكفاءته الحرارية منخفضة، ويطلق كميات كبيرة من غاز الديزل العادم والحرارة المفقودة في الغلاف الجوي، مما يستبب في هدر الموارد الضخمة فضلاً عن هدر الطاقة. ومن أجل حماية البيئة وتوفير الطاقة، وأيضاً من أجل حل هذه المشاكل الخاصة بإعادة تدوير غاز العادم واسترداد الحرارة المفقودة، تم احتساب معدل انبعاث العادم من محرك الديزل Z12V190 والحد الأدنى من معدل حقن الغاز للحفر التخلخلي ومقارنتها مع المعدلات السابق استنتاجها. وقد تم حساب ضغط النقطة الحركة لمجموعة من أنابيب الحفر مختلفة القطر لنفس قطر البئر، والتي أثبتت جدوى استخدام غاز العادم لمحرك الديزل Z45V190 في الحفر التخلخلي. وفي الوقت نفسه، تم احتساب معدل استرداد الحرارة المفقودة كما أثبتت الجدوى الاقتصادية لاستخدام غاز العادم لمحرك الديزل Z45V190. لقد تم تصميم رسم تخطيطي لعملية الحفر باستخدام غاز العادم لمحرك الديزل Z45V190 وكيفية استغلال الحرارة المفقودة. سيتم إعادة تدوير غاز العادم لمحرك الديزل Z45V190 للحد من التلوث، واسترداد الحرارة المفقودة من أجل توفير موارد الطاقة.

كلمات البحث: محرك الديزل، غاز العادم، الحفر التخلخلي، إعادة التدوير، استرداد الحرارة المفقودة.

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- سلسلة التقارير الدورية.
- سجل الأحداث الجارية لمنطقة الخليج والجزيرة العربية وجوارها الجغرافي.
- مجلدات وثائق مختارة لمنطقة الخليج والجزيرة العربية وجوارها الجغرافي.

سلسلة الإصدارات

سلسلة علمية محكمة

تُعنى موضوعاتها بمنطقة الخليج والجزيرة العربية، وتهدف إلى إبراز خصوصيتها، ورصد قضايا التنمية بأبعادها الحضارية الشاملة في ضوء المتغيرات الجارية.

قواعد النشر

أولاً : أن يكون البحث أو (الدراسة) معنية بشؤون منطقة الخليج والجزيرة العربية في المجالات الآتية: السياسة، الاقتصاد، الجغرافيا، التاريخ، علم النفس، الاجتماع، الأنثروبولوجيا، التربية، اللغة العربية وآدابها، الثقافة، البيئة، القانون، الإعلام ، التراث (الآثار والحضارة والفنون) .

ثانياً: أن تمثل الدراسة إضافة جديدة إلى حقل التخصص.

ثالثاً: لم يسبق تقديمها أو جزء منها للنشر إلى جهة أخرى.

رابعاً: ألا يقل عدد صفحات البحث أو (الدراسة) عن ١٠٠ صفحة.

خامساً: يقدم المركز مكافأة مالية رمزية عن كل دراسة.

الاشتراكات

نوع الاشتراك	الكويت	الدول العربية	الدول الأجنبية
الأفراد	٤ د.ك	٤ د.ك	١٤ دولاراً
المؤسسات	٢٥ د.ك	٢٥ د.ك	٦٨ دولاراً

المراسلات

توجه جميع المراسلات باسم مدير المركز

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مجلة الشريعة والدراسات الإسلامية

فصلية علمية محكمة تصدر عن مجلس النشر العلمي بجامعة الكويت

تعنى بالبحوث والدراسات الإسلامية

رئيس التحرير الأستاذ الدكتور: عبدالعزيز خليفة القصار

صدر العدد الأول في رجب ١٤٠٤هـ – أبريل ١٩٨٤م

* تهدف إلى معالجة المشكلات المعاصرة والقضايا المستجدة من وجهة نظر الشريعة الإسلامية.
* تشمل موضوعاتها معظم علوم الشريعة الإسلامية: من تفسير، وحديث، وفقه، واقتصاد وتربية إسلامية، إلى غير ذلك من تقارير عن المؤتمرات، ومراجعة كتب شرعية معاصرة، وفتاوى شرعية، وتعليقات على قضايا علمية.
* تنوع الباحثون فيها، فكانوا من أعضاء هيئة التدريس في مختلف الجامعات والكليات الإسلامية على رقعة العالمين: العربي والإسلامي.
* تخضع البحوث المقدمة للمجلة إلى عملية فحص وتحكيم حسب الضوابط التي التزمت بها المجلة، ويقوم بها كبار العلماء والمختصين في الشريعة الإسلامية، بهدف الارتقاء بالبحث العلمي الإسلامي الذي يخدم الأمة، ويعمل على رفعة شأنها، نسأل المولى عز وجل مزيداً من التقدم والازدهار.

جميع المراسلات توجه باسم رئيس التحرير

ص.ب ١٧٤٣٣ – الرمز البريدي: 72455 الخالدية – الكويت هاتف: ٢٤٨١٢٥٠٤ – ٢٤٩٨٤٧٣٣ – ٢٤٩٨٨٠٩٥

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