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MODIFICATION OF THE EXHAUST PIPING SYSTEM FOR COGENERATION UNIT REDEVELOPMENT

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УСОВЕРШЕНСТВОВАНИЕ КОГЕНЕРАЦИОННОЙ УСТАНОВКИ МОДИФИКАЦИЕЙ КОНСТРУКЦИИ ЕЁ ВЫХЛОПНОЙ СИСТЕМЫ

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This paper deals with the exhaust piping modification in order to modify a open-form cogeneration unit into container form. Moreover, proposed design takes into account exhaust piping back-pressure, which is according requirements specified by the engine manufacturer. Double-way exhaust piping of 350 mm diameter is used. It consists of pipe, catalyst, heat exchanger, bypass, electronically controlled flaps, bent pipes and two silencers. Proposed solution also consider space restrictions, emission scattering and operation noise point of view. Proposed solution was checked for the desired piping back-pressure according modern standards. Two variants were investigated – when the exhaust gases flows through bypass, and when flowing through heat exchanger. By calculations were checked expected low values of proposed piping system back-pressure, what make him able to be used in newly produced cogenerating units.
Key words: *cogeneration unit, exhaust piping, back-pressure, emission dispersion, noise.*

Introduction. Cogeneration units (Cogeneration or combined heat and power – CHP unit) are nowadays very requested devices. The role of cogeneration itself is production of multiple types of energy at the same time. This device allows you to reduce energy costs. CHP unit can achieve up to 40% energy savings, thereby greatly increasing interest of customers in cogeneration units. An advanced form of cogeneration is trigeneration in which electrical energy and cold from heat can be obtained.

There are many complexes (aquaparks, sports centers, shopping centers, factories, industrial parks) where cogeneration can be used to save energy costs or can be used for complexes located in more abandoned places. CHP unit can be designed in different performance classes. Its performance depends on the used engine and it is possible to produce devices in range from a couple of kW up to several MW. The CHP unit can be produced in versions powered by various fuels, whether liquid or gaseous.

Design of CHP unit can be enclosure, container and open. A frequent application is to set the device in the hall or machine room. This is a very practical solution due to possible servicing and quick access to all components of the unit. On the other hand, if the conditions require construction of a compact and easily stored unit, the CHP units can be made in a container design. In this embodiment, the unit becomes relatively space saving and easily moveable [2].

This paper describes the design of an exhaust system for a new container version of the same assembly in an open design. The design of the exhaust system is not intended to optimize performance. Unit is designed to comply with the maximum allowed exhaust pipe back-pressure given by the engine manufacturer.

Design of the original exhaust system

The original exhaustion system is adapted to the hall where the cogeneration unit is stored. For an optimal characteristics the exhaust pipe of an inner diameter of 350 mm is used. As can be seen in fig. 1, the exhaust pipe begins in a corner on the side of the cogeneration unit housing and opens to the catalyst. It is also led alongside the CHP unit, where a heat exchanger from the flue gas is located along with the bypass. At the heat exchanger are electronically controlled dampers that direct the flow of residues either to the bypass or to the heat exchanger. From the bypass and the heat exchanger, the pipeline runs through two 45-degree knee pipes out of the building. From the outside of the hall, we can see two noise mufflers pointing perpendicularly upwards as shown in fig. 1b) in order to bring the residues above the building into the air. System of two mufflers can be used to achieve best results. The first muffler is resonant usually in combination with the second muffle, which is absorptive. Due to the fact that the CHP unit is in a residential area, two muffler system have been used, which reduce noise very well to an acceptable limit. A supporting structure is provided around the silencers to ensure the stability of the exhaust system.

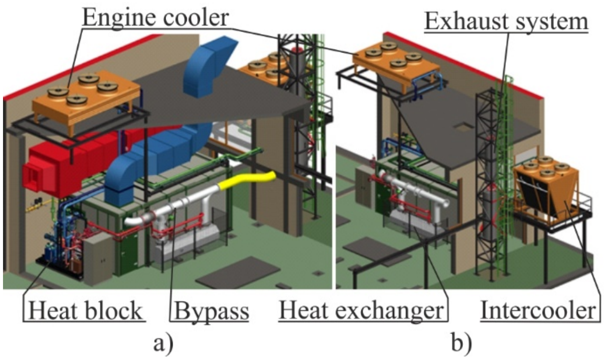

Fig. 1. 3D model of the cogeneration unit
a – internal view, b – external view

Requirements for the new solution

In this case, CHP unit will be located near the residential area. There will be 3 identical devices, each with a capacity of 1 MW. Location where the devices are situated does not contain a hall, therefore customer decided to use a container construction.

Design prepositions:

- space limitations,
- emission dispersion and noise damping,
- final design of the exhaust.

All three devices are installed next to each other and the customer has placed the engine cooling, intercooler and air conditioning on the roof of the container. Our task was to design the exhaust pipe in the space remaining for us (Fig. 2). For our design the most important dimension was the distance between the ventilation openings and the radiator pipes, which is 3560 mm.

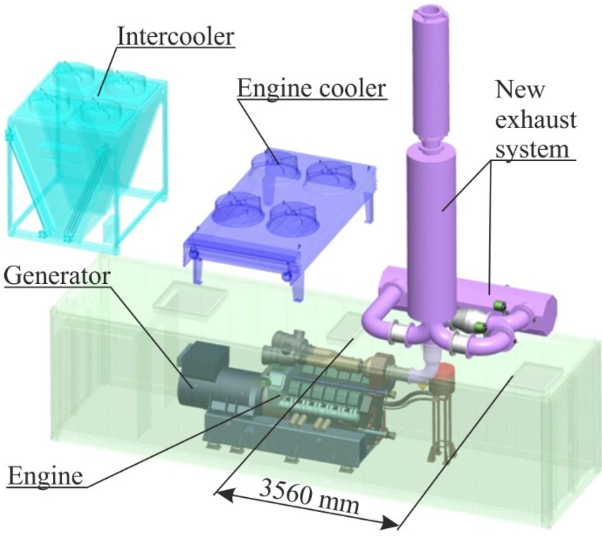

Fig. 2. Space constraint on the roof of the container

Emission dispersion and noise control

Emission dispersion is a very important factor in the planning of the exhaust system when it comes to decision where the emissions will be released. The new cogeneration unit will be located in close proximity to the residential area, where it is necessary to release the fumes at the highest point as possible and thus the appropriate solution is to direct the outlet of the exhaust pipe vertically upwards to achieve maximum possible height of exhaustion [7].Two solutions were used to reduce noise.

First possibility is to use a multi-muffler system where is used by experiences verified combination a series of mufflers where the first is resonant and the second absorber. If only one muffler would be used, it would not be able to reduce the noise by more than 30 dB. In the case of installation two muffler system, a total damping of noise up to 45 dB [5, 6] is achieved.

The second possibility is to divert exhaustion outlet to upright and the exhaust noise to move from the living area.

The most ideal solution concerning the location of CHP unit is to use both solutions at the same time to achieve the lowest noise levels and highest fume particles dispersion.

Final design proposal of the exhaust pipe

According to previously described conditions the following solution (Fig. 2) is reached. The exhaust pipe is located on the roof of the cogeneration unit container. Immediately, after the first bending of exhaustion pipe, the inner diameter of pipe is enlarged from 250 mm to 350 mm. These values have been recommended by the manufacturer based on previous experiences with construction of CHP unit.

Our proposal is verified with validating calculation in order to keep satisfying dimensions of exhaustion system for specified engine (fig. 3). After expansion of the pipe (A), it flows into the catalyst (B). The catalyst is followed by the flue gas distribution (C) to either the bypass (G) or the heat exchanger (D) [3]. Exhaustion pipe from the heat exchanger as well as from the bypass is connected to the lead (F) to the first noise muffler (H). The first noise muffler is followed by previously mentioned second muffler (H). Direction of the exhaust pipe on the basis of the previous points is designed from the point of origin to the first noise muffler upright. This solution has advantages in low noise generation and low space requirements.

It is also desired to mention that any bending of exhaust system is not allowed due to presence of coolers, which needs to keep proper distance from hot mufflers. Possible bending of exhaustion pipe in a different direction from the coolers would also not be a good solution because only direct vertical solution is easy to stabilize with only using steel ropes. Possible bending would require an auxiliary structure and we would also reduce the amount of flue gas leakage from the ground, which means we would not follow the emission and noise damping requirements.

The final design of the exhaust system

Fig. 3 shows final design of the exhaust pipe with description. Fig. 2 shows the designed exhaust system located on the CHP unit's roof. Free space under the coolers has been used for air conditioning of the equipment.

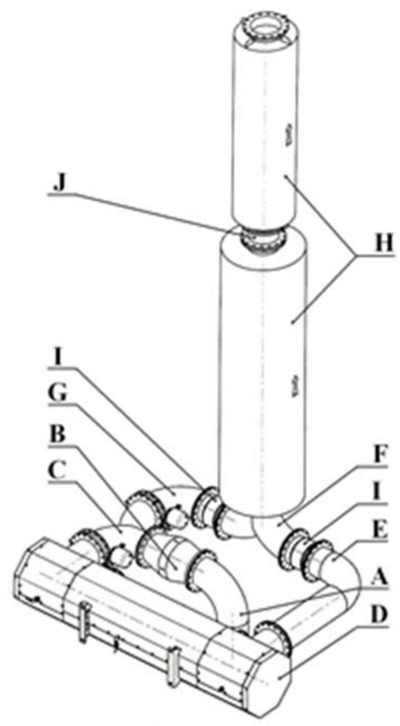

Fig. 3 CHP unit exhaust system assembly
(A-exhaust pipe, B-catalyst, C-exhaust manifold,
D-heat exchanger, E-exhaust duct, F-exhaust manifold,
G- bypass, H- silencer, I- axial compensator, J-clutch)

Verifying calculation

Validating and iterative calculations verified the outgoing back-pressure of the designed exhaust pipe [1]. It's minimum and maximum limits are given by the engine manufacturer in his technical description. In this case, for the MWM TCG 2020 V12 1MW engine, the exhaust backpressure value is from 30 to 50 mbar. [8]. Calculation is based on the data given by the manufacturer of the exhaust pipe. We used Diesel Installation Manual from the PERKINS's company specification. As described in [4], the calculation is made as follows:

- entering values of the maximum allowed backpressure in mm Hg,
- entering of backpressure values of used components (catalytic converter, shock absorber and heat exchanger),
- calculation of the backpressure value of the proposed piping system,
- summary of the backpressure values and the comparison with the maximum allowed backpressure value of the engine.

In this case, two calculations have to be made as the exhaust system has two variants of the exhaust gas pipe. The first variant is to conduct exhaust gases through the heat exchanger, which is referred to as *Exhaust system with cold exhaust gas*. The second variant is the exhaustion flow through the bypass, which, however, does not cool the exhaust gases. We designate this variant as *Exhaust system with hot exhaust gas*.

Exhaust system with cold exhaust gas

The allowed exhaust back-pressure of the manufacturer is converted to units of mm Hg of P_{pdov} = 22.05 to 37.51 mm Hg.

Exhaust system backpressure values:

- catalyst (P_{Cat}) - 1200 Pa - 9 mm Hg,
- heat exchanger (P_E) - 600 Pa - 4.5 mm Hg,
- 1 muffler (P_{S1}) - 700 Pa - 5.25 mm Hg,
- 2 muffler (P_{S2}) - 50 Pa - 0.38 mm Hg.

For calculations of back-pressure are used formulas (1 - 4) where the inner diameter of the pipe determines the theoretical length of the straight pipe, which achieves the same back-pressure as the proposed bended pipe.

$$L_K = D.15 \quad (1)$$

where L - pipe length, m; D - inner diameter of the pipe segment, m.

For calculating the back-pressure, the inner diameter of the pipe is again used in the calculation. Result is the theoretical length of the straight pipe, which has the same back-pressure as the real, bended exhaust pipe.

$$L_Z = D.30 \quad (2)$$

To calculate the axial compensators, the relationship is then slightly modified.

$$L_A = D.2 \quad (3)$$

Following formula is used to calculate the extension of pipe from a diameter of 250 mm to 350 mm.

$$L_P = D.31 \quad (4)$$

For straight pipes, their actual length in meters is given.

By calculation, the final length L was obtained, representing the final air resistance adequate to pipe of length 48.692 m. According to previous formula (5) we have calculate final back-pressure of pipe 3.62 mm Hg.

$$P = \frac{L.Q^2}{D^{5,33}}.1187.10^9 \quad (5)$$

where P - exhaust pipe back-pressure, mm Hg; L - the total length of the exhaust pipe, m; Q - the amount of flue gases listed in the specification [8], kg/s; D - inner diameter in the exhaust pipe (larger), mm.

The calculated back-pressure of the exhaust pipe system is added to the back-pressure of the corresponding components and the total exhaust back-pressure of the exhaust system. According formula (6) final back-pressure of exhaust system P_c = 22.75 mm Hg was calculated.

$$P_C = P + P_{Cat} + P_E + P_{S1} + P_{S2} \quad (6)$$

Table 1

Exhaust system with cold exhaust gas

Pipe section according Fig. 3	Description and formulas	Theoretical length, (m)
Part 1 of Part A	straight piece, it's length is l = 0.079 m	0.079
	knee pipe with internal diameter D = 0.25 m, according formula (1)	3.75
Part 2 of Part A	extension from diameter, D = 0.25 m to D = 0.35 m, according formula (4)	10.8
Part 3 of Part A	a straight piece, it's length is l = 0.5 m	0.5
	knee pipe with internal diameter D = 0.35 m, according formula (1)	5.25
Part C	duct with internal diameter D = 0.35 m, according formula (2)	10.5
Part E	straight piece with length l = 1.07 m	1.07
	knee pipe with internal diameter D = 0.35 m, according formula (1)	5.25
	straight piece with length l = 0.165 m	0.165
Part I	axial compensator with length l = 0.3 m, according formula (3)	0.6
Part F	duct with internal diameter D = 0.35 m, according formula (2)	10.5
Part J	Constriction between the buffers of length l = 0.228 m	0.228
	∑L	**48.692**

After comparing of the entered values it can be stated that the designed exhaust system with cold exhaust gas fulfills parameters specified by the engine manufacturer.

Exhaust system with hot exhaust gas

Allowed exhaust back-pressure is up 22.05 to 37.51 mm Hg.

Exhaust system back-pressure parameters are:

- Catalyst (P_{Cat}) - 1200 Pa (9 mm Hg),
- 1 muffler (P_{S1}) - 1200 Pa (9 mm Hg),
- 2 muffler (P_{S2}) - 100 Pa (0.75 mm Hg).

Calculation of back-pressure of the proposed pipeline is based on values in Tab. 2.

The total pipe length of the exhaust system L will be used in formula (5) and the value of the exhaust back-pressure is 3.52 mm Hg.

The result of the total backpressure of the exhaust system according to the formula (6) is 22.27 mm Hg.

After comparing the entered values, it can be stated that the designed exhaust system with hot exhaust gas also meets the parameters given by engine manufacturer.

Table 2

Exhaust system with hot exhaust gas

Pipe section according Fig. 3	Description and formulas	Theoretical length (m)
Part 1 of Part A	straight piece, it's length is l = 0.079 m	0.079
	knee pipe with inner diameter D = 0.25 m, according formula (1)	3.75
Part 2 of Part A	extension from diameter, D = 0.25 m to D = 0.35 m, according formula (4)	10.8
Part 3 of Part A	a straight piece, its length is l = 0.5 m	0.5
	knee pipe with inner diameter D = 0.35 m, according formula (1)	5.25
Part C	duct with inner diameter D = 0.35 m, according formula (2)	10.5
Part G	bypass with inner diameter D = 0.35 m, according formula (1)	5.25
Part I	axial compensator with length l = 0.3 m, according formula (3)	0.6
Part F	duct with inner diameter D = 0.35 m, according formula (2)	10.5
Part J	constriction between the buffers of length l = 0.228 m	0.228
	∑L	**47.457**

Conclusion

This paper deals with redesign of a open form CHP unit to container version. In order of this modification we redesigned exhaust system to make possible to place it on the container roof. Final design consists of exhaust pipe, catalyst, flue gas distributor, heat exchanger, flue gas duct, bypass, several mufflers, axial compensators, a constriction between the mufflers and a relatively compact and engine no loading flue gas. According to verifying calculation we confirmed estimations about low back-pressure and so final design can be used for construction of exhaust pipe of new CHP unit.

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Павлік А., Хаусер В., Кравченко К. Удосконалення когенераційної установки модифікацією конструкції її вихлопної системи

У статті представлені результати досліджень з удосконалення конструкції когенераційної установки. Дані установки дозволяють зберігати до 40% вартості енергії і широко розповсюджені як в закритих об'єктах, так і на відкритих просторах. У дослідженнях вирішувалося завдання досягнення необхідних параметрів установки для відводу вихлопних газів при зменшених розмірах для використання в контейнерах на відкритих просторах. Витяжна система містить два канали діаметром 350 мм. До основних частин системи відносяться труби, каталізатор, теплообмінник, байпас, клапани з електронним управлінням, вигнуті труби і два глушника. При розробці модернізації конструкції враховувалося емісійне розсіювання, експлуатаційний шум, просторові обмеження, сучасні стандарти для системи відведення вихлопних газів. Для оцінки доцільності використання запропонованої конструкції проведені два варіанти розрахунків: при проходженні вихлопних газів через байпас і другий варіант - через теплообмінник.

Ключові слова: *когенераційна установка, витяжна система, протитиск, емісійне розсіювання, шум.*

Павлик А., Хаусер В., Кравченко Е. Усовершенствование когенерационной установки модификацией конструкции её выхлопной системы

В статье представлены результаты исследований по усовершенствованию конструкции когенерационной установки. Данные установки позволяют сохранять до 40 % стоимости энергии и широко устанавливаются как в закрытых объектах, так и на открытых пространствах. В исследованиях решалась задача достижения требуемых параметров установки для отвода выхлопных газов при уменьшенных размерах для использования в контейнерах на открытых пространствах. Вытяжная система содержит два канала диаметром 350 мм. К основным частям системы относятся трубы, катализатор, теплообменник, байпас, клапаны с электронным управлением, изогнутые трубы и два глушителя. При разработке модернизации конструкции учитывалось эмиссионное рассеивание, эксплуатационный шум, пространственные ограничения, современные стандарты для системы отвода выхлопных газов. Для оценки целесообразности использования предложенной конструкции проведены два варианта расчётов: при прохождении выхлопных газов через байпас и второй вариант – через теплообменник.

Ключевые слова: *когенерационная установка, вытяжная система, противодавление, эмиссионное рассеивание, шум.*

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