Micro Turbines – A Literature Mini Review

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MICRO TURBINES : A LITERATURE MINI-REVIEW

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ABSTRACT

This literature mini-review highlights the remarkable progress and diverse applications of microturbines in various industries. Microturbines offer pragmatic and efficient options for electricity generation, from renewable energy generation to use in industrial complexes and residential environments.

Research on microturbines has examined a number of design elements aimed at improving their performance and ensuring economic sustainability. These factors include the number of blades, integration of subsystems and thermoeconomic modelling.

The development of domestic micro-ORC systems and the improvement of working fluids emphasize the importance of considering fluid properties, efficiency and environmental impact in microturbine design.

Research into the integration of micro gas turbines into homes and small waste disposal sites contributes to sustainability goals by highlighting the potential for decentralized energy production and waste repurposing.

Efforts to improve the efficiency of micro Tesla turbines provide valuable insights into increasing efficiency and scalability in microturbine technology.

As a result, microturbines are emerging as a promising path for sustainable energy production and decentralized energy grids. Continuous research and innovation in this field is essential to fully utilize its capacities and meet the growing demand for clean and efficient energy solutions.

Keywords : Micro turbine, MGT, Tesla turbine

1. INTRODUCTION

Today, there is an increasing need to focus on sustainability in the field of energy production and use. In this context, microturbines attract attention as compact and effective devices that play an important role in electricity production by utilizing renewable energy sources. Microturbines generate electricity using energy from wind, water and other sources and are often used in a variety of applications, from industrial facilities to homes and small businesses. Micro turbines, first designed by Italian inventor Lucien Gambarota, have been developed and different models have been created according to different usage areas and needs [1]. Various studies and their results in the literature on microturbines are stated and explained below.

A study has shown that micro turbines with a large number of blades (6 and above) are generally more efficient, but there is not enough research on the applicability of micro wind turbines in residential areas, the effects of environmental parameters on micro turbines, the number of blades of micro turbines and their performance at different wind speeds with different diameters [1].

Another study in this field focuses on independently designing complex subsystems of microturbines and then integrating these systems in a digital environment and operating them in harmony at a certain performance level. In the study, the subsystems of the microturbine system are: compressor and turbine duo, combustion chamber, exchangers required for recuperation and waste heat recovery, oil and water tanks, pumps and alternator for electricity generation. Using an interdisciplinary simulation environment such as MATLAB/Simulink, mathematical models were developed for each subsystem. These mathematical models are created based on physical principles. In order to ensure consistency between subsystems, it was modeled parametrically by experts from different disciplines, starting from the design footprint and considering the interfaces and performances of the matching models. In line with the requirements of the design, the compressor and gas turbine set to be used through external supply was selected. This choice allowed manufacturing requirements to be met and performance requirements to be met. Afterwards, mathematical models of all physical systems were prepared and integrated into the Simulink model, and a parametric micro-turbine model was created. The turbine model was designed to be compatible with the compressor and combustion chamber models, and an industrial performance map was selected to produce torque and power in line with the design targets. Finally, the reliability and realism of the model were tested and an environment was provided for studies on a fully autonomous digital engine controller (FADEC) [2].

Two different scenarios were examined in a thesis study aiming to develop a thermoeconomic model that enables the evaluation of using a micro steam turbine instead of a pressure reducer used in industrial facilities that require steam at different pressures and providing extra electricity production. In the first scenario, only a micro steam turbine investment is made,

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while in the second scenario, a larger capacity steam boiler and micro steam turbine investment is made. According to the study results, it has been shown that both scenarios can be more efficient and economical in terms of thermodynamics. However, it has been determined that the first scenario has a shorter payback period and a higher internal profitability rate. In the first scenario, 44.35 kW of electrical power is produced from the turbine. The net present value of the investment is 7,558,132 TL (Turkish Lira), the internal rate of return is 41.17% and the payback period is 4 years and 11 months.

In the second scenario, 89.51 kW of electrical power is produced from the turbine. The net present value of the investment is 7,260,836 TL, the internal rate of return is 31.62% and the payback period is 8 years and 1 month. It has been determined that working hours, escalation rate and discount rate are effective on the results for both scenarios. In particular, it has been concluded that it can be an economic investment for facilities where the pressure difference between low pressure processes and high pressure processes is high or for facilities operating with high steam flow [3].

In another thesis study, the design of a 10 kW micro hydro turbine was carried out starting with empirical and analytical methods. The power of the design made in the first stage was calculated as approximately 9.5 kW by computational fluid dynamics (CFD) analysis. However, by using CFD analysis and optimizing various parameters, the power was increased up to 12 kW. This study emphasizes that only CFD analyzes are not sufficient in turbine design and that finite element analysis (FEA) is also necessary to evaluate structural strength. The mechanical design was made taking into account production technologies and it was recommended to use standard pipes in the body manufacturing for cost-effective solutions. During the design process, production techniques such as CNC (Computer Numerical Control) machined rotor and more simply designed stator bent from sheet metal were used. However, wings bent from sheet metal may cause loss of efficiency and power because they cannot provide a 3-dimensional profile. This design method can be used for any fixed-blade response turbine, and adjustable blades have been proposed to accommodate variable flow rates and heads in medium to high power turbines. As a result, domestically designed hydro turbines can reduce foreign dependency and be considered as alternative energy sources for countries with high hydroelectric potential. Mini and micro turbines can be used as alternative energy sources in areas where electricity transmission is difficult [4].

Another study examined the energy production and cost associated with 30 kW microturbines using biogas at small landfills. Levelized Cost of Electricity (LCOE) method was used in the economic evaluation. With a capacity factor of 0.80, annual electricity production per microturbine reached 210,240 kWh. Taking turbine-specific costs into account, the projected levelized electricity cost for a 30 kW microturbine with an 8% discount rate is estimated at $0.079 per kWh. Taking the increase into account, the levelized cost ranged from $0.091 to $0.116/kWh. These findings show that the use of a 30 kW microturbine powered by biogas is both economically feasible and technically feasible for small landfills [5].

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In a study, the usability of micro gas turbines was investigated to meet the energy needs of a ten-storey residential building located in cities such as Tehran, Ahvaz and Hamedan. These turbines used natural gas as an energy source. The excess electrical energy of the micro gas turbines was used in a heat pump/cooling system to meet the heating/cooling needs of the building. Additionally, the energy in the turbine's exhaust gases met the remaining heating/cooling and hot water needs of the building using a heat exchanger/absorption cooling system. Recommendations have been made for buildings with high heating and cooling loads and the use of a minimum number of turbines is recommended. It is stated that the example building in Tehran has an electrical power demand of approximately 33 kW and that micro gas turbines, one with a nominal capacity of 40 kW or two with a nominal capacity of 30 kW, can be used to meet this demand [6].

Another study shows examples of indigenous micro-ORC systems for several working fluids, along with thermodynamic and microturbine analyses. It is emphasized that the final selection of the working fluid is not only about performance, but also greatly depends on the fluid's price, toxicity, explosiveness, availability, environmental impact and other factors.

It has been shown that turbines achieving acceptable efficiencies can be designed for very small powers. Examples of such microturbines are presented for MM, acetone and cyclopentane. For acetone and cyclopentane, a turbine with 62% efficiency at a rotation speed of 200 krpm can be designed, while for MM the best turbine efficiency is equal to 71% at a rotation speed of 100 krpm.

The results show that analysis of the expansion unit allows better prediction of system performance. Under the assumption that the combined turbine efficiency is equal to 60%, the net system efficiency is calculated as 8.0%, 8.5%, and 8.3% for MM, acetone, and cyclopentane, respectively. The system efficiency for the best turbine efficiencies (71%, 62% and 62%) is 9.5%, 8.8% and 8.6% respectively (MM, acetone and cyclopentane). This proves that the fluid that was previously thought to have the worst performance among these three fluids actually performs the best [7].

Another study examines the performance and miniaturization of micro Tesla turbines and obtained several important results. In a Tesla turbine, the flow passes through many small channels around the rotor. These channels, arranged on the outer surface of the rotor, allow the flow to move perpendicular to the rotor's axis of rotation. This arrangement allows the flow to move along the axis of rotation rather than in a rotational motion, unlike conventional turbines. With the miniaturization method proposed in this study, isentropic efficiency increased by reducing the turbine size. Studies have shown the effects of turbine size on mass flow and power. Additionally, it has been determined that the isentropic efficiency of micro-multichannel turbines increases as the disk outer diameter decreases. These results are considered an important step to understand the performance of micro Tesla turbines and improve their miniaturization [8].

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2. THERMAL MODELING

Thermal modeling will be included based on the principles in a sample study [9]. According to this study, microturbine is a small-sized gas turbine based on the Brayton cycle that operates with approximately 30% thermal efficiency. Figure 1 shows a schematic diagram of a microturbine in a Combined Heat and Power (CHP) system. To increase the efficiency of microturbines and reduce fuel consumption, there is a recuperator in front of the combustion chamber to use the turbine exhaust gases to heat the inlet air of the microturbine. Recuperators increase the energy recovered from exhaust gases by increasing the thermal efficiency of the microturbine cycle [9,10]. Most microturbines have a single-stage centrifugal turbine and compressor, and exhaust gas flow rates are generally between 0.3 and 2.3 kg/s [9,11]. Environmental conditions significantly affect the operating parameters of the microturbine, such as power output and efficiency. These operating parameters decrease with increasing atmospheric temperature and altitude [9,12]. Moreover, features such as microturbine characteristics, efficiency, exhaust gas temperature and exhaust gas flow rate in part and nominal load operations are basic data for analyzing a CHP system [9].

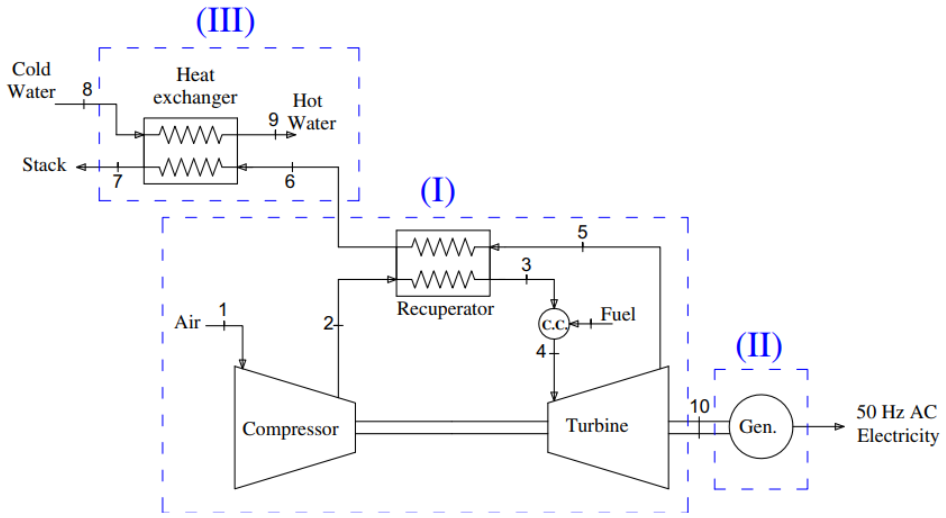

Figure 1. The schematic diagram of a microturbine in combined heat and power system,2009 [9]

The microturbines selected as drivers of CHP systems and their operating characteristics at nominal load are given in Table 1.

Table 1. The selected microturbines as the driver of CHP systems and their operating specifications at nominal load [9]

Microturbines[a]					Operating fuel gas

	Power output, W (kW)	Thermal efficiency, η (%)	Gas mass flow rate, m_G (kg/s)	Exhaust temperature, T_{Ex} (°C)	pressure, P_f (psi)[b]
A	30	26	0.31	275	55
B	60	28	0.49	305	75
C	65	29	0.49	309	65
D	70	27	0.73	232	70
E	75	25	0.68	260	65
F	80	26	0.83	278	80
G	80	28	0.74	280	70
H	100	30	0.8	271	80
I	100	29	0.79	293	78
J	250	29	2.3	242	100
K	350	31	2.27	315	135

a : Equivalent (virtual) name for commercial brands in the market
b : This unit of pressure is usually listed in microturbine catalogs

Micro gas turbine operates on the principles of Brayton open gas/air cycle. The cycle is represented in temperature-entropy (T-s) and pressure-volume (p-v) diagram as shown in Figures 2 and 3. In Brayton open cycle the engine working fluid exit/exhaust into the atmosphere after expansion in the turbine and/or the exhaust propelling nozzle [13].

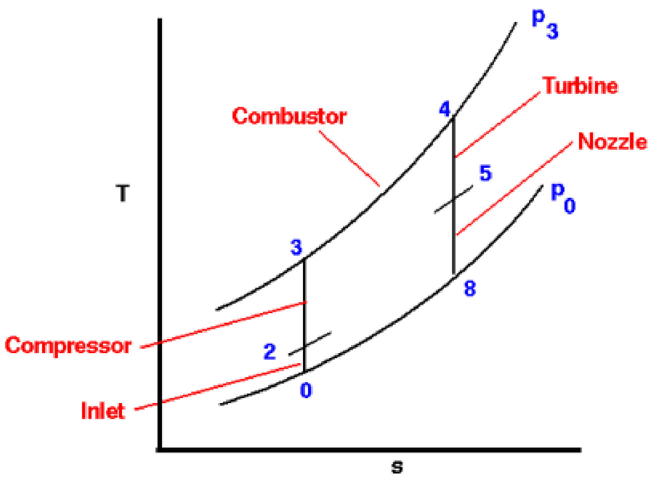

Figure 2. T-s diagram of micro gas turbine,2015 [13]

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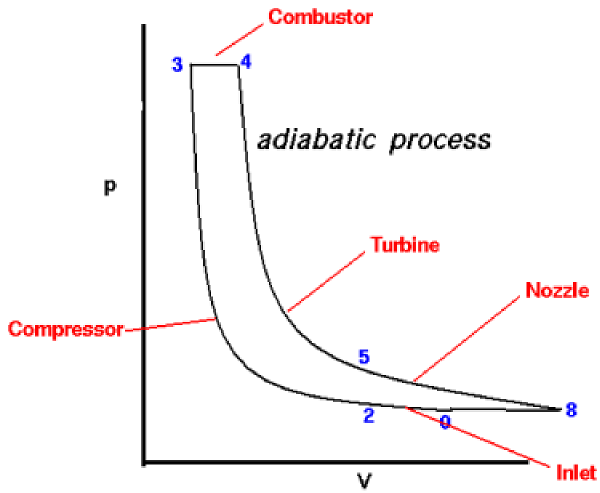

Figure 3. **P-v diagram of micro gas turbine,2015 [13]**

The cycle is assumed to be isentropic air compression, heat addition at constant pressure, isentropic gas expansion, and heat rejection at constant pressure. In practice, these processes are not isentropic. As shown in Figures 2 and 3, isentropic compression occurs in the compressor at position 0-3, constant pressure heat addition occurs in the combustion chamber at position 3-4, isentropic expansion occurs in the turbine at position 4-5, isentropic in the nozzle at station 5-8 work is done and finally heat is rejected from 8-0 to atmosphere at constant pressure [13].

From Figures 2 and 3 the compressor ratio and efficiency are determined as using these relations:

$$\pi_c = \frac{p_{03}}{p_{00}} \quad (1)$$

$$\eta_c = \frac{T_{00}(\pi_c^{\frac{\gamma-1}{\gamma}} - 1)}{T_{03} - T_{00}} \quad (2)$$

Once the compressor parameters are determined, the thermodynamic characteristics or quantities of combustion are derived. Typically, the decrease in pressure during combustion is represented as a fraction of the stagnation pressure downstream of the compressor. The highest temperature expected in the engine cycle is calculated as:

$$T_{04} = T_{03} + \frac{\eta_{cc} f LHV}{c_{pg}} \quad (3)$$

Applying the principles of work and speed compatibility the turbine upstream temperature is computed.

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$$T_{05} = T_{04} - \frac{\dot{m}_a c_{pa}(T_{03} - T_{00})}{\dot{m}_g c_{pg} \eta_m} \quad (4)$$

With known turbine parameters the nozzle thermdynamic values are determined. Having estimated the nozzle exhaust velocity the engine thrust is found, thus for propulsion purposes.

$$F_{net} = \dot{m}_a (u_e - u_0) \quad (5)$$

Similarly, for electrical power generation application the power can be determined using the required formula [13].

3. VISUALIZATION OF A MICRO GAS TURBINE ENGINE

A microgas turbine engine, shown in Figure 4, is a single-shaft rotary engine that extracts energy from the flow of microcombustion gas. The engine is a miniature copy of larger conventional gas turbine engines. Their thermal efficiencies generally vary between 10% and 25%, and power and thrust capacities can be in the range of 15-300 kW and 30-200 N, with rotational speeds between 20,000 and 150,000 rpm. The engine usually consists of a centrifugal compressor, radial or crossover vane diffuser, an annular straight or counterflow combustion chamber, axial flow turbine, and a fixed convergent thrust nozzle at the fluid outlet of the engine [13].

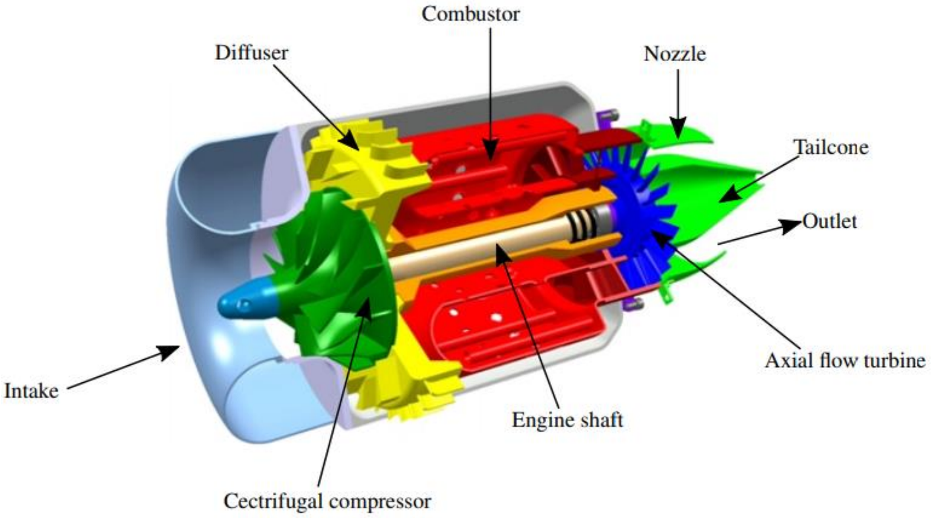

Figure 4. Micro gas turbine engine,2015 [13]

During the process, the engine's centrifugal compressor draws air from its surroundings into the engine. It compresses air to increase its total pressure and temperature. The compressor diffuser reduces its speed as it passes through divergent passages (vanes), which increases air passage and lowers its static pressure. Low-speed air mixes with fuel in the combustion chamber and

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burns continuously, producing high temperature, high pressure and fast gas. The turbine produces mechanical shaft power by expanding the high-temperature gas coming from the combustion process and drives the compressor. Convergent exhaust thrust nozzle is used to provide thrust by accelerating the exhaust gases coming from the turbine [13].

Micro gas turbine layout is given in Figure 5 [14].

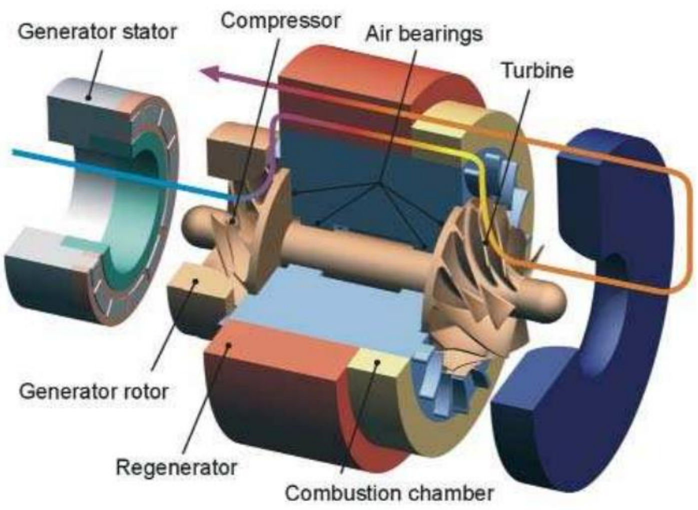

Figure 5. Micro gas turbine layout,2005 [14]

4. CONCLUSIONS

The research presented in this literature mini-review highlights the significant advances and different applications of microturbines in various industries. Microturbines offer practical and effective solutions for electricity generation, from renewable energy production to industrial facilities and residences.

Studies on microturbines have investigated various design factors to improve their performance and ensure their economic availability, including elements such as number of blades, integration of subsystems, and thermoeconomic modelling.

The development of domestic micro-ORC systems and optimization of working fluids emphasizes the importance of considering fluid properties, efficiency and environmental impact in microturbine design.

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Studies examining the use of micro gas turbines in residences and small landfills contribute to sustainability goals by highlighting the potential for decentralized energy production and waste recycling.

Research on miniaturization and performance enhancement of micro Tesla turbines provides important information for increasing efficiency and scalability in micro turbine technology.

Overall, microturbines stand out as a promising solution for sustainable energy production and decentralized power systems. Further research and innovation in this area is critical to unlock their full potential and meet the demand for clean and efficient energy solutions.

REFERENCES

[1] Yasin, İ. Ç. E. L. (2023). Mikro Rüzgâr Türbin Modelleri Üzerine Bir Araştırma. Avrupa Bilim ve Teknoloji Dergisi, (47), 47-52.

[2] Sarı, O., Bulat, O., Tunçer, O., & Üçler, Ç. (2020). Model Tabanlı Tasarım ile Eş-Zamanlı Mühendislik: Mikro-Türbin Uygulama Örneği. Engineer & the Machinery Magazine, 61(698).

[3] Akgün, İ., Pusat, Ş., & Erdem, H. H. (2022). Thermo-economic investigation of power generation using micro steam turbines in industrial facilities.

[4] Öztürk, E. (2012). Bir mikro hidro türbinin tasarımı analizi ve deneysel incelenmesi.

[5] Gökçek, M. (2017). Waste to Energy: Exploitation of Landfill Gas in Micro-Turbines. Omer Halisdemir University Journal of Engineering Sciences, 6(2), 710-716.

[6] Ehyaei, M. A., & Bahadori, M. N. (2007). Selection of micro turbines to meet electrical and thermal energy needs of residential buildings in Iran. Energy and Buildings, 39(12), 1227-1234.

[7] Klonowicz, P., Witanowski, Ł., Jędrzejewski, Ł., Suchocki, T., & Lampart, P. (2017). A turbine based domestic micro ORC system. Energy Procedia, 129, 923-930.

[8] Qi, W., Deng, Q., Yuan, S., & Chen, B. (2023). Advantages of the aerodynamic performance of micro-Tesla turbines. Energy Science & Engineering, 11(5), 1734-1752.

[9] Sanaye, S., & Ardali, M. R. (2009). Estimating the power and number of microturbines in small-scale combined heat and power systems. Applied Energy, 86(6), 895-903.

[10] Pilavachi, P. A. (2002). Mini-and micro-gas turbines for combined heat and power. Applied thermal engineering, 22(18), 2003-2014.

ISBN NO : 978-625-6283-01-5

[11] Onovwiona, H. I., & Ugursal, V. I. (2006). Residential cogeneration systems: review of the current technology. Renewable and sustainable energy reviews, 10(5), 389-431.

[12] Technology characterization–microturbine. Energy Nexus Group, USA Environmental Protection Agency; 2002.

[13] Oppong, F., Van Der Spuy, S. J., & Diaby, A. L. (2015). An overview on the performance investigation and improvement of micro gas turbine engine. R & D Journal of the south african institution of mechanical engineering, 31, 35-41.

[14] Peirs, J., Verplaetsen, F., Driesen, J., Belmans, R., Puers, R., Verstraete, D., ... & Reynaerts, D. (2005). Micro power generation based on micro gas turbines: a challenge. MST NEWS, 4, 37.