COMPARATIVE ANALYSIS OF STEAM GENERATORS FUELED BY LIGNITE AND HARD COAL FROM EMISSIONS POINT OF VIEW

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Abstract: When comparing two steam generators first thing we think about is their effectiveness. As the environmental impact of industrial activities is a topic becoming more actual lately, an analysis of steam generators from this point of view was considered appropriate. Two steam generators were chosen based on their long-term operation period, almost the same construction and different fuel types used to power them. The results show the need for the replacement of the steam generators as both have exceeded the pollutant concentration limits, and modern steam generators have higher efficiency.

Key words: steam generator, efficiency, emission factor, concentration of pollutant, lignite, hard coal

1. INTRODUCTION

Energy efficiency is an issue with ever growing importance, and objectives regarding this topic are stated in Directive 2012/27/EU on energy efficiency.

In this directive, the necessity to increase energy efficiency in the Union to achieve the objective of saving 20 % of the Union's primary energy consumption by 2020 compared to projections [1] is highlighted.

Another important aspect of modern economy with increasing importance, as sign of global warming are occurring more often, is the reduction of greenhouse gas emissions. As acknowledged in Kyoto Protocol, now in the second commitment period, global warming exists and human-made CO_2 emissions have caused it.

The importance of reduction of greenhouse gas emissions is emphasised by the ever-growing number of laws and regulation in EU [2].

On the other hand, energy efficiency and green gas emissions are strongly connected, as higher efficiency industrial processes require less energy which translates in lower emissions as fuel consumption decreases.

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Steam generators used in industrial applications are expensive equipment, with a long life-cycle, and a great majority of steam generators produced 40 years ago, are still in use. At that time, global warming was not an issue, so as the environmental impact of industrial activities is a topic becoming more actual lately, an analysis of steam generators from this point of view was considered appropriate.

2. REVIEW OF ANALYSED STEAM GENERATORS

Two steam generators were chosen, CRG-1666 and Pp-330/140-P55 (Fig. 1.) based on their long-term operation period, almost the same construction and different fuel types used to power them.

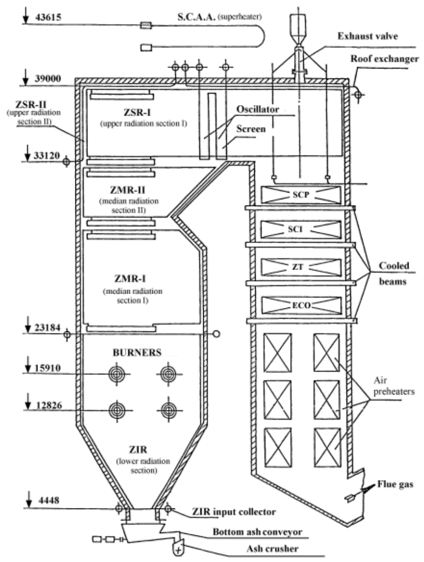

Fig. 1. Pp-330/140-P55 steam generator

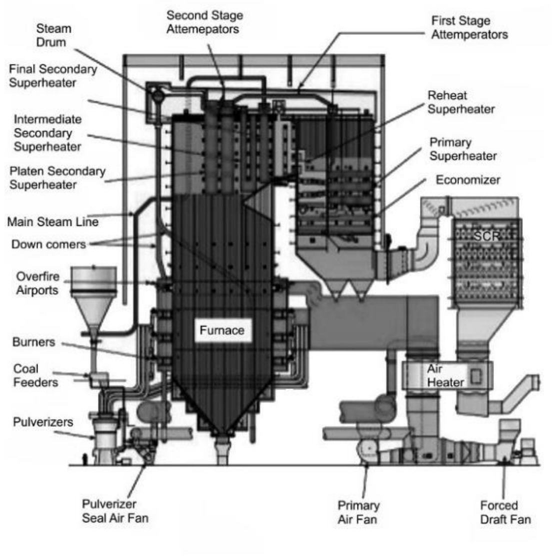

Fig. 2. Water tube boiler (steam generator) [3]

Construction of Pp-330/140-P55 steam generator is carried out in two distinct bodies, operating in parallel to the steam turbine. The steam output of generator (one body) is 330 $t \cdot h^{-1}$, at a pressure of 140 bar and 550 °C for live steam and 24.4 bar at 550 ºC temperature for reheat steam. Each steam generator body Fig. 1 is designed with two flue gas paths - in the shape of Π - one ascending and one descending, tied together with a reverse room. Abbreviations in Fig. 1: SCAA - steam-steam heat exchanger, ZSR I, II - upper radiation section, ZMR I, II – median radiation section, ZIR – lower radiation section, SCP - primary convection superheater, SCI - intermediate convection superheater, ZT – transition section, a convection phase-change section where conversion of water into steam is terminated and the formed steam is superheated by about 20-30 ºC, ECO – economizer, PA – regenerative air heater (SCAA and SCI are part of the reheater circuit). Fuels used in furnace chamber can be solid (pulverized coal), liquid (heavy fuel oil) or gaseous (natural gas).

The ascending path is the furnace chamber area, where the radiation heat exchangers are located and the descending path consists in the convection heat exchange surfaces. Combustion air and the air used for the transport of pulverized coal are blown by a centrifugal air fan. The basic fuel is crushed coal, obtained in hammer mills (4 mills for each body of the steam generator). To start and support the flame, auxiliary fuel is used (natural gas or heavy fuel oil).

CRG-1666 is a water tube steam generator (Fig. 2) with natural circulation, two Π shaped flue gas paths, a steam drum and 420 $t \cdot h^{-1}$ steam output at 137 bar pressure and 540 °C temperature. The rated efficiency is 85%. The rated feed water temperature is 230 °C at 158 bar pressure.

The steam drum is a horizontal cylinder holding a large volume of water, placed on the upper part of the steam generator, from which the down comers are supplied with water. In the steam drum, the liquid phase is separated from the steam.

The water drum is fed with water using feedwater pumps through the economizer where the water is preheated at 230 ºC. In the economizer, the water is heated using flue gases from the second flue gas path. As a result, the temperature of water is near the vapor temperature. In the vapor circuit: steam drum – water wall – drum a natural circulation occurs. The water reaches vapor temperature (approximately 345 ºC) and the liquid phase is separated in the steam drum. The vapours are superheated in the platen and the rear superheater of the second flue gas path, side walls of second flue gas path, I, II, III and IV superheater. These heat exchange surfaces are connected one after another on the steam side. Finally steam temperature reaches 540 ºC.

Between I and II superheater and II and III+IV superheater attemperators are placed, injecting feed water in order to regulate steam temperature.

3. MEASURED DATA AND CALCULUS

Energy auditing in Romania is regulated by the state and supervised by the regulatory authority ANRE, and must be carried out according to the published guide [4] and the review of emissions is part of the energy auditing. Algorithms and equations for heat balance calculations of various installations and equipment can be found in literature [5], [6].

The investigated units are equipped with a data acquisition and process control systems in order to track boiler operating parameters. In order to perform a proper heat balance analysis at least 3 different load must be taken into account.

As the Pp-330/140-P55 steam generator has two distinct bodies, and a perfect balance between the loads it is practically impossible, for each load, two sets of measurements were performed. The two bodies will be denoted with letter A and B.

The loads for performance tests for Pp-330/140-P55 steam generator were fixed to 230 $t \cdot h^{-1}$ – 69.70%, 280 $t \cdot h^{-1}$ – 84.85% and 310 $t \cdot h^{-1}$ – 93.94% , while those for CRG-1666 where at 70.20%, 85.60% and 95.80%.

In addition to data obtained from data acquisition systems of boilers, measurements are carried out in order to obtain more accurate data on combustion. Using a TESTO 350 portable emission and combustion analyser, data on flue gas composition, flue gas temperature T_{ga} and coefficient of excess air λ is obtained, Table 1.

During measurements coal samples were taken in order to obtain data on composition and lower heating value of the used coal and lignite (Table 2.).

Tabel 1. **Flue gas composition**

Nom.	**U.M.**	**Pp-330/140-P55**						**CRG-1666**		
		69.70%		**84.85%**		**93.94%**		**70.20%**	**85.60%**	**95.80%**
		A	**B**	**A**	**B**	**A**	**B**			
O_2	%	10.69	9.54	8.46	8.01	8.16	8.47	7.6	7.2	8.1
CO	%	$4\cdot10^{-4}$	$4\cdot10^{-4}$	$2\cdot10^{-4}$	$5\cdot10^{-4}$	$3\cdot10^{-4}$	$5\cdot10^{-4}$	0.038	0.03	0.177
CO_2	%	8.45	8.99	11.11	11.01	10.77	10.4	12.8	13.2	12.3
SO_2	%	0.1	0.1	0.2	0.2	0.1	0.1	0.021	0.022	0.0006
NO	%	0.0	0.0	0.0	0.0	0.0	0.0	0.02	0.009	0.009
T_{ga}	°C	174.5	176.1	183.2	181	175	172.1	151.3	156.7	152.9
λ		2.01	1.79	1.66	1.6	1.61	1.65	1.56	1.51	1.61

The basic fuel is crushed coal for Pp-330/140-P55 steam generator and lignite for CRG-1666. To start and support the flame, auxiliary fuel is used: natural gas for Pp-330 and heavy fuel oil in case of CRG-1666.

Table 2. **Lower heating value of coal, lignite, natural gas and heavy fuel oil**

Load [%]	**Pp-330 A body**	**Pp-330 B body**	**CRG-1666**	**Natural gas**	**Heavy fuel oil**
	Lower heating value kJ·kg^{-1}				
Min.	15,746.75	14,959.49	6,597.8	34,851.0	40,668.0
Med.	14,355.70	14,556.09	6,632.6	34,851.0	40,668.0
Max.	14,252.93	13,896.65	6,592.5	34,851.0	40,668.0

From emissions point of view the composition is important, as a result, in Table 3 the elemental analysis of heavy fuel oil, lignite and hard coal is given.

Table 3. **Elemental analysis of heavy fuel oil, lignite and hard coal**

Nom.	**Symbol**	**Heavy fuel oil composition, r%**	**Lignite composition, r%**	**Hard coal composition, r%**
Carbon	C	87.73	25.60	37.2
Sulphur	S	0.37	0.56	1.7
Hydrogen	H_2	10.65	1.08	2.8
Oxygen	O_2	0.70	6.85	7.6
Nitrogen	N	-	1.01	0.7
Nitrogen (gas)	N_2	0.15	-	-
Humidity	W	0.20	-	-

Humidity overall	W_t	-	41.00	12.8
Ash	A	0.20	23.90	37.2
Total, %		100,00	100.00	100.00

While the composition of natural gas is: CH_4 – 98.51%, C_2H_4 – 0.8 %, O_2 – 0.2%, N_2 - 0.49%. The flue gas rate needed for calculus of pollutant concentration in flue gas results from balance sheet calculation already performed in paper [7] and listed in Table 4 along with the fuel mixture flow rate. Based on data above, the carbon and sulphur content of the fuel mixtures were calculated.

4. RESULTS AND CONCLUSIONS

The energy assessment of the boilers provided different data on the analysed steam generators. In Fig. 3 net energy efficiency and gross thermal efficiency is presented as function of load.

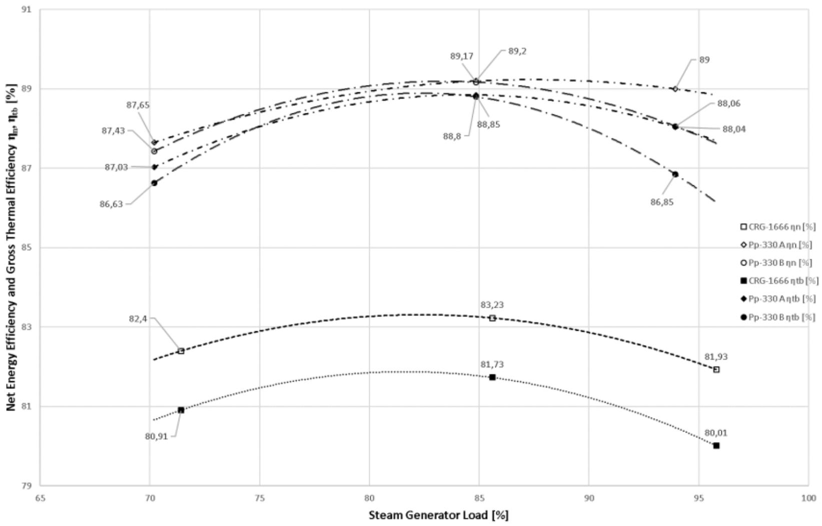

Fig. 3. Net Energy Efficiency and Gross Thermal Efficiency

From efficiency point of view, the Pp-330/140-P55 steam generator is more efficient. The comparison with data from literature [8] the efficiency of lignite fired steam generator is good (81.73 % compared with 79.05 %) but there is room for improvement, since using lignite pre-drying efficiency may rise up to +4% [9]. Regarding the efficiency of hard coal fired steam generator data in literature points to efficiency rates up to 91.90 % [10] values close to the efficiency of analysed steam generator. From emission factors point of view (Fig. 4, 5, 6 and 7), results are pointing out that CO_2 and dust emission factor is higher for CRG-1666 steam generator while SO_2 emission factor is higher for Pp-330 steam boiler, as they are proportional to the carbon, ash and sulphur content of the fuel. The NO_x emission factor is higher for the Pp-330 steam generator.

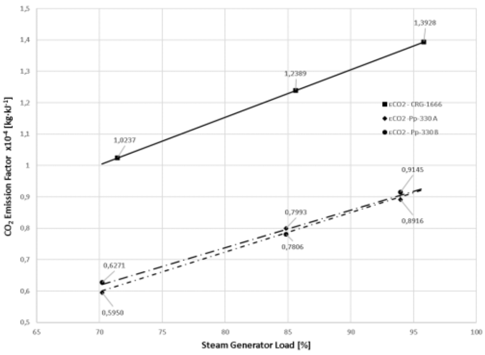

Fig. 4. CO_2 Emission Factor

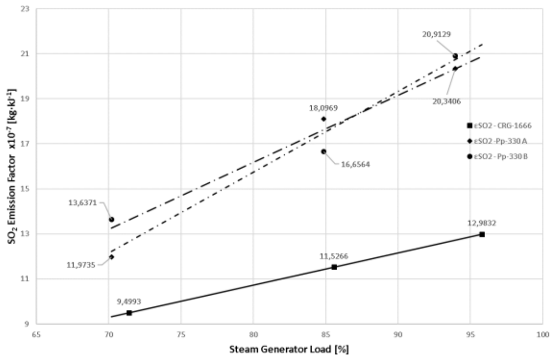

Fig. 5. SO_2 Emission Factor

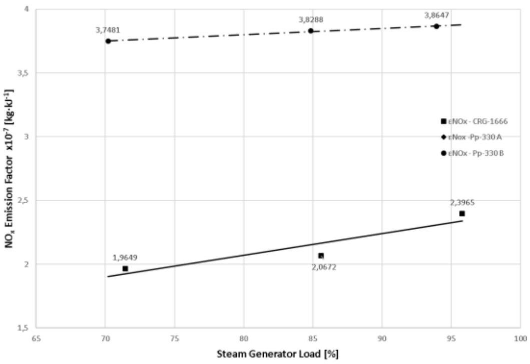

Fig. 6. NO_x Emission Factor

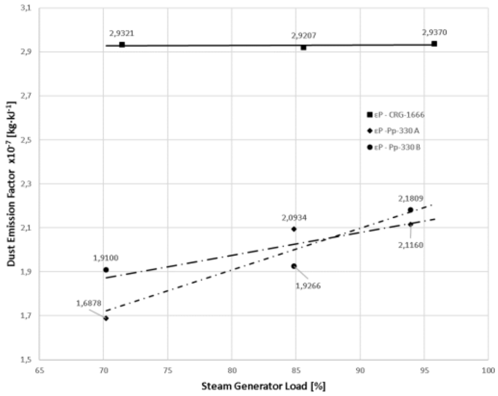

Fig. 7. Dust Emission Factor

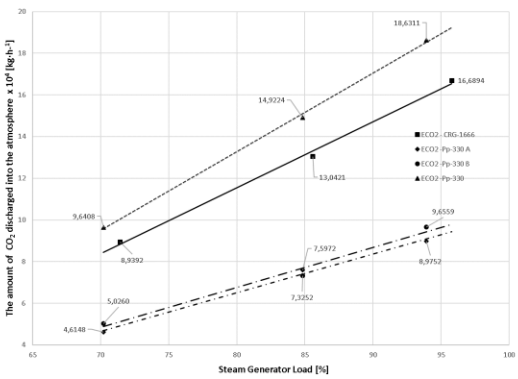

Fig. 8. The Amount of CO_2 Discharged

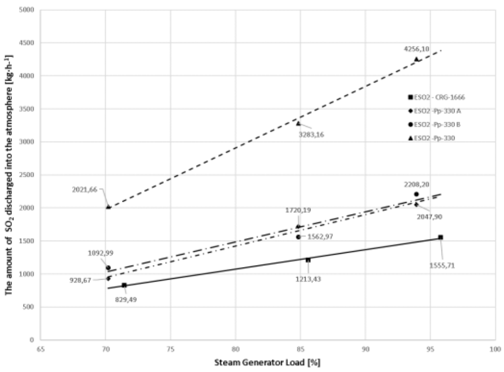

Fig. 9. The Amount of SO_2 Discharged

In Fig. 8, 9, 10 and 11 the amount of pollutants discharged in the atmosphere are presented. The amount of pollutants complies with proportions of emission factors, but since the Pp-330 steam generator consist of two bodies operating in parallel, the sum of pollutants discharged in the atmosphere for the two bodies is higher.

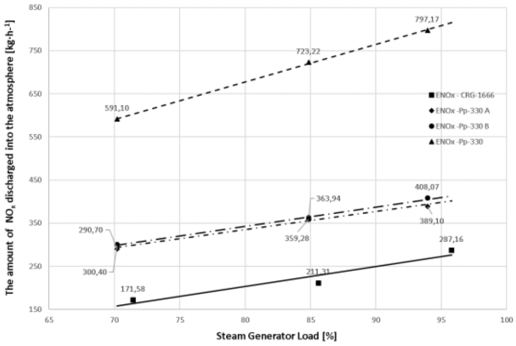

Fig. 10. The Amount of NO_x Discharged

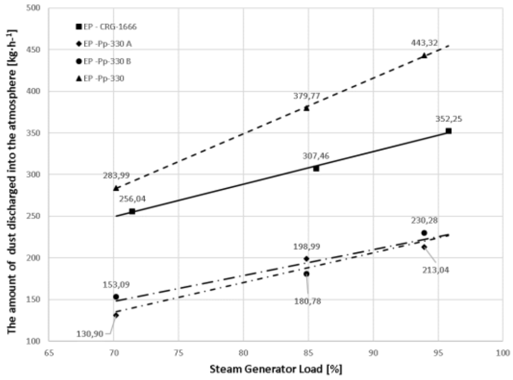

Fig. 11. The Amount of Dust Discharged

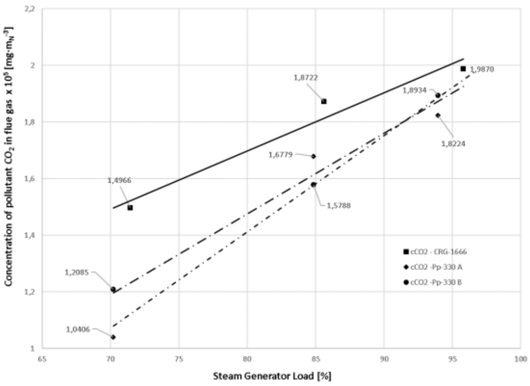

Fig. 12. Concentration of Pollutant CO_2

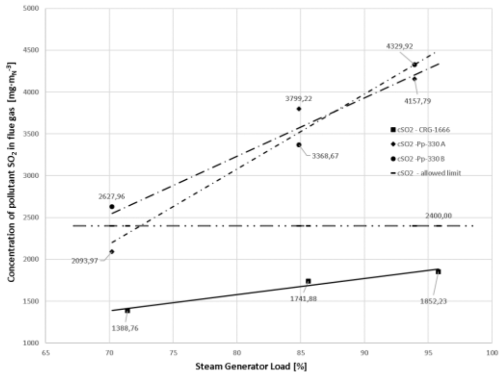

Fig. 13. Concentration of Pollutant SO_2

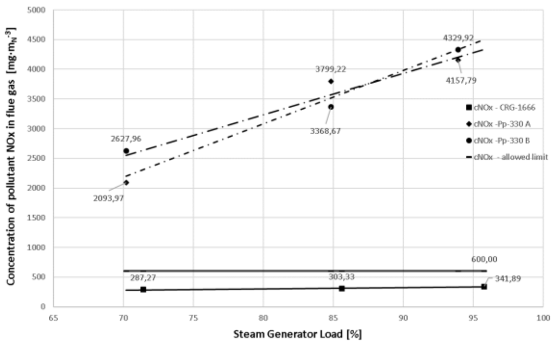

Fig. 14. Concentration of Pollutant NO_x

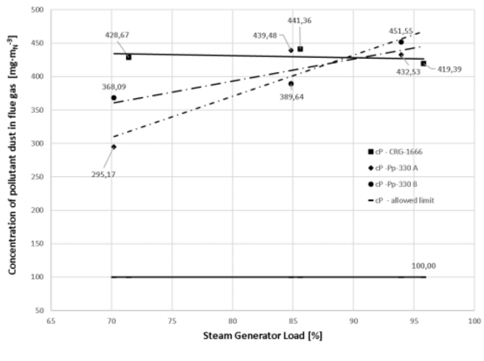

Fig. 15. Concentration of Pollutant Dust

In Fig. 12, 13, 14 and 15 the concentration of the pollutants in flue gas is presented. In terms of environmental protection, they are important indicators. The concentration of SO_2 and NO_x is under the allowed limit for the CRG-1666 steam generator, while the dust concentrations exceeds the allowed limit for both steam generators. For SO_2 complying with the allowed limit can be achieved by using fuel with low sulphur content, wet flue gas cleaning and gypsum production [9], while NO_x reduction can be achieved using specialized burners. Dust reduction can also be achieved using electrostatic filters with 99.8% capture rate [9].

Conclusively the studied steam generators have performances according to the technologies existing at the time when produced. Complying with environmental standards can be achieved, but retrofitting them could lead to efficiency loss [11].

Since retrofitting in order to comply environmental regulations, along with efficiency loss can bring significant capital investments, the best solution could be replacing the steam generators as they are close to the end of their life-cycle. This solution could solve both issues regarding energy efficiency and complying to environmental standards.

REFERENCES:

[1]. http://ec.europa.eu/energy/efficiency/eed/eed_en.htm

[2]. https://ec.europa.eu/clima/about-us/climate-law_en

[3]. http://www.slideshare.net/MohammadShoebSiddiqu/steam-generator-part-2

[4]. ***, *Guide to development and analysis of energy balance*. M.O. of Romania, part. I, nr.792/11.11.2003.

[5]. **Carabogdan, I. G., et al.,** *Energy Balances*. Tehnica Publishing House, Bucharest, (1986).

[6]. **Berinde, T., et al.,** *Elaboration and analysis of energy balance in the industry*. Tehnica Publishing House, Bucharest, (1976)

[7]. **Dosa, I.,** *Energy Performance of Steam Generator after Its Long-Term Operation*, "9th WSEAS International Conference on ENERGY, ENVIRONMENT, ECOSYSTEMS and SUSTAINABLE DEVELOPMENT" (EEESD '13), Lemesos, Cyprus, March 21-23, ISBN: 978-1-61804-167-8, pp. 65-70, 2013

[8]. **Chetan, T. P., Bhavesh, K. P., Vijay, K. P.,** *Efficiency with different GCV of Coal and efficiency improvement opportunity in boiler*, ISSN: 2319-8753, IJIRSET, Vol.2, Issue 5, 2013

[9]. http://okolje.arso.gov.si/ippc/uploads/File/4_Lignite_power_plants_en.pdf

[10]. **J. Y. Lu, X. F. Lu, G. Yin, H. Z. Liu,** *Heat Balance Analysis of Baima's 300 MWe CFB Boiler in China*, Proceedings of the 20th International Conference on Fluidized Bed Combustion, Springer Berlin Heidelberg, 2010, pp 496-501, ISBN: 978-3-642-02681-2, http:// dx.doi.org/10.1007/978-3-642-02682-9_76

[11]. **Zhang, D., Xu, M. and Li, A.** (2012), *Techno-economic analysis of a 300 MWe coal-fired power plant retrofitted with post-combustion* CO_2 *capture.* Asia-Pacific Jrnl of Chem. Eng, 7: S201–S208. doi: 10.1002/apj.614.