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Productivity evaluation of water purification process by means of heat transformer

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Industrial Engineering looks for a productivity improvement to the process so as to grow and increase its profitability. The companies' engineers need to measure and compare their rates with a target in order to know if they are profitable. This article proposes calculating the labour and capital productivity rates for a Heat Transformer that has been used in the process of water purification, taking into consideration factors such as productive work (research time and test), the workplace (Applied Thermal Engineering Laboratory, LITA 2), materials, machinery and equipment (powers obtained by the absorber, the generator and transformer evaporator heat) called the Capital. The rate of productivity is defined as the ratio of outputs in a period of time over the time spent by workers in the production of goods. This ratio indicates the participation of labuor in the volume of production.

1 Introduction

The objective of this analysis is to calculate the productivity rates for economical factors called labour and capital. The heat transformer (HT) is operated with a mixture of water - lithium bromide, located at laboratory of applied thermal engineering (LITA 2) of the Center of Investigation in Engineering and Applied Sciences (CIICAp) from the Universidad Autonoma del Estado de Morelos (UAEM). This is used in a water purification process, developed by Silva (2007) in the thesis Experimental study system of water purification assisted by a heat transformer with a generator and an absorber with an area of transference modified.

The Productivity is an economic indicator that is defined as the amount of output made in a period of time over the hours that have been spent by workers on the production of these goods in the same period of time. In other words the productivity indicates to us how many products have been generated with all the resources used in an economic activity. There are four classic productive synergistic factors associated with the productivity: materials, machinery and equipment (which is known as the Capital),

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work place, and labuor. According to Kons (1990) the factor material represents the inputs used for the production of good or service and the factor machinery and equipment represents the technology with which the process is worked, the work place factor represents the area where the productive activity is carried out, finally the labour factor represents the period of time needed to execute the work. The most important productivity rates are: total productivity that involve all the factors and secondly partial productivity like labour productivity and capital productivity INEGI (2003).

A heat transformer (HT) is a type of *"heat bomb"* which can improve the heat quality from industrial waste and heat from conventional sources at higher levels of temperature, using only energy in form of heat with a hundredth part of mechanical energy in order to circulate the work fluids internally. Its basic elements are a generator, a condenser, an evaporator and an absorber.

The generator is an element whose function is to produce work fluid vapor from the concentrated solution under specific conditions of temperature, with any source of heat, Rayon (2007). A condenser is an element whose function is to change vaporized work fluid to liquid phase; this process has been performed to a lower temperature than the system temperature Romero (2005). The evaporator function is to change the liquid phase of work fluid to saturated vapor, using half temperature Casillas (2008). Finally the absorber function is to receive the vaporized work fluid from the evaporator, after the vapor is absorbed by the solution of concentrated lithium bromide at higher temperature (TA) than the vapor, releasing large quantity of useful heat. Casillas (2008).

Finally the coefficient of performance (COP) which is defined as the relationship of heat provided by the absorber divided by the heat from the generator plus the heat from the evaporator Romero (2000).

2 Methodology

2.1 Identification of productive factors

In the first place we have to identify the synergistic productive factors such as workplaces, machinery and equipment, labour and materials and identify the product generated during the process.

2.2 Calculation of production volume (PV) and hours men worked (HMW)

Once the product has been identified we proceed to measure the volume of product obtained during the test period, after that sorting the information per day, finally quantities must be summed to obtain the final quantity of product. In the case of HWM is necessary to establish which time was spent on the operation of the HT in order to know exactly the labour time and eliminate any other time spent on other activity different to the test operation of the HT.

2.3 Calculation of productivity labour rate

To calculate the labour productivity the following formula has been proposed:

$$PLR_{HT} = \left(\frac{PV_{QAB}}{HMW} \right) * 100 \qquad (1)$$

Where PLR_{HT} is the rate of labour productivity of the HT. PV_{QAB} is the production volume of heat provided by the absorber and HMW are the man hours spent in the oparation of HT

2.4 Calculation of the rate of capital productivity
From the formula of COP we have proposed a new formula to calculate the capital productivity.

$$PCR_{HT} = \left(\frac{Q_{AB} * ECC}{(Q_{GE} + Q_{EV}) * IC} \right) * 100 \qquad (2)$$

Where PCR is the rate of capital productivity of the HT. Q_{AB} is the heat provided by the absorber. ECC is the commercial cost of energy. Q_{GE} is the heat produced by the generator. Q_{EV} is the heat produced by the evaporator. IC is the indirect cost of energy transformation by the HT.

3. Case of application

3.1 Identification of productive factors
Work place: Is the Applied Thermal Engineering Laboratory, LITA 2.
Man Hours Worked: Is the period of spent time of research in the operation of HT.
Machinery and equipment: The heat transformer.
Materials: Heat provided by the absorber

Table 1. Shows the man hours spent in the operation, the total heat produced by the absorber in kW and the Productivity labour rate.

	Date	**MHW- hours**	**QAB - kW**	**PLR_{HT}**
Test 1 stage II	07-Jul	8.25	0.35	**4.24**
Test 2 stage II	08-Jul	12.08	0.05	**0.41**
Test 3 stage II	13-Jul	12.05	0.00	**0.00**
Test 4 stage II	15-Jul	8.58	0.00	**0.00**
Test 5 stage II	20-Jul	10.59	0.98	**9.25**
Test 6 stage II	23-Jul	13.11	0.79	**6.03**
Test 7 stage II	28-Jul	21.42	0.60	**2.80**
Test 8 stage II	03-Aug	5.92	0.52	**8.78**
Test 9 stage II	16-Aug	4.95	0.69	**13.94**
Test10 stage II	17-Aug	8.85	0.00	**0.00**
Test11 stage II	18-Aug	7.23	0.30	**4.15**
Test12 stage II	19-Aug	3.94	0.94	**23.86**
Total		116.97	5.22	**PLR_{HT}**

3.2 Calculation of production volume (PV) and man hours worked (MHW)

From the results record generated during the investigation, we have taken the values of heat provided by the absorber (Q_{AB}) every day during the performance. If one day has more than one reading we get an average per day.

Table 1 shows the production volume of Q_{AB} per day and the total amount of product produced during the test period. It is important to clarify that the water production is not our final product because the system that we are measuring is the HT and its product the useful heat. In the case of MHW we have choose only the time spent by the researcher in the test operation of the HT. The total number of hours worked by the researcher per day, is important to clarify that the time spent on other activities such as maintenance of equipment was eliminated from the results and only one person has participated on the test operation.

3.4 Calculation of the rate of capital productivity

The table 2 shows the rate of capital per day of the HT calculated form the formula (2). The total hours involved in the generation of useful heat is the same quantity of MHW. Thus the direct costs of power generation in an HT is zero, however according to the World Energy Assessment, United Nations (2000) there are indirect costs that should be considered, hence the value cost considerate was 0.35 USD kW per hour for the heat which is generated by the generator (Q_{GE}) and evaporator (Q_{EV}). Moreover, according to the Bulletin of the National Committee for the Study of AC power. Southern region of the CFE form Mexico (2007) the commercial cost per hour for the useful heat generated by the absorber (Q_{AB}) is 0.4 USD kW (which represents the selling price if this energy will be sold).

Table 2. Productivity Capital rate produced from the COP values.

	Date	**Q_{AB} -kW**	**Q_{EV} -kW**	**Q_{GE} - kW**	**PCR_{HT}**
Test 1 stage II	07-Jul	0.35	1.08	0.88	**20.41**
Test 2 stage II	08-Jul	0.05	0.25	0.52	**7.42**
Test 3 stage II	13-Jul	0.00	0.57	0.76	**0.00**
Test 4 stage II	15-Jul	0.00	0.00	0.00	**0.00**
Test 5 stage II	20-Jul	0.98	2.34	2.43	**23.48**
Test 6 stage II	23-Jul	0.79	2.30	2.07	**20.66**
Test 7 stage II	28-Jul	0.60	1.86	1.60	**19.82**
Test 8 stage II	03-Aug	0.52	1.39	1.68	**19.36**
Test 9 stage II	16-Aug	0.69	2.49	2.04	**17.41**
Test10 stage II	17-Aug	0.00	0.00	0.00	**0.00**
Test11 stage II	18-Aug	0.30	0.77	0.97	**19.70**
Test12 stage II	19-Aug	0.94	2.40	2.23	**23.20**

4. Results and discussion

The proposed formulas have allowed us to know about the behavior of economic factors of a HT designed specifically to provide useful heat to a water purification system in fact, table 1 shows, a PV_{QAB} of 5.22 kW generated during all the test operation, it means we have a product that could be sold. As a result, this represents a successful design of HT. Additionally, it lets us know the period of time that one researcher has spent per day on the operation test. Unfortunately 116.97 hours spent by a research is more than we were expecting. However, there are two scenarios, in table 1, test number 7 which has 21.42 hours worked with only 0.6 kW of PV_{QAB} therefore its PLR_{HT} is only 2.80% percent, it shows us that there are operation problems that should be fixed. The second scenario, the best test was the number 12 which has only 3.94 MHW representing the less spent time by the researcher through the test operation, with 0.94 kW of PV_{QAB} and a PLR_{HT} of 23.86%, representing the highest labour productivity rate that has been calculated. *If we compare both rates 2.8% and 23.86% there is a growth on the operation of 852% at the final of the project. The time spent by researcher is clearly productive.* As a result, we can establish 23.83% like a base of our PLR_{HT}, which will be used as the minimum amount of PLR that could be obtained for others HT with a similar design.

Table 2, shows all the PCR_{HT} obtained in the operation. In the cases with Q_{AB} equal to zero is unfortunately unprofitable process, however there are tests with a reasonable PV (Do not forget, the test was made in a small laboratory HT), for example the test 5 has the highest PCR_{HT} from the project, obviously has a higher PV than other tests. Hence we have established 23.48 like a base of our PCR_{HT} as a target that has to improve for future investigations.

Moreover is important to analyze, why there are two different productivity rates, for one side the PLR_{HT} says the best productivity rate is from the test 12 with 23.86 % and the other one the PCR_{HT} says the best productivity rate is from the test 5 with 23.48%. It is easy to explain both productivity rates represent different economic factors. The PLR_{HT} represents the workers participation and its growth. In the case of PCR_{HT} represents the capital (materials and machinery) and its growth even though the last test day the productivity rate decreases despite having 0.94 kW of PV.

Finally our most important result is that, we have measured and analyzed economic behavior of heat transformer used labour and capital rates to establish a productivity target for new designs.

5. Conclusion

We have proposed the use of productivity rates in order to evaluate the test operation of a Heat Transformer has used in the process of water purification. The benefit obtained with this measure is that now we can know as much as the economic factors have been grown during the production process of Q_{AB}. In the case of PLR_{HT} *there is a growth on the operation of 852% at the final of the project hence it is a productive labour rate* compared with the test with more MHW spent in the project. As a result of this research we have gotten two productivity targets that must be improvement for new designs of HT, one for PLR_{HT} of 23.86 and one more for PLC_{HT} of 23.48.

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