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MODEL BASED ON BOOLEAN LOGIC FOR SCREENING AND SELECTION OF THE ARTIFICIAL LIFT METHODS

Mark Malatinszky [1]

Mariea Marcu [2]

[1] Bsc, Petroleum-Gas University of Ploiesti, **Romania**
[2] Petroleum-Gas University of Ploiesti, **Romania**
e-mail: malatinszky.mark@gmail.com; mmarcu@upg-ploiesti.ro

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Abstract

Artificial lift methods are used in oil wells when the natural energy of the reservoir is not enough to bring the reservoir fluids at the surface. Therefore, these methods are used to add the missing energy. There are many types of artificial lift methods with different characteristics. The selection of an artificial lift technique for a well is crucial because it influences long-term well production and operating costs. In our paper, we propose an application that allows a quick screening and selection of the best artificial lift technique. The application uses Boolean logic as a mathematical and conceptual approach. The model is based on a memory set of data which is working like a database and compares the information in order to select the best artificial lift method for a well data set. The results are presented in two layers such as a front page used for input data set and a second one where it will be displayed the selected method and its advantages and disadvantages.

Keywords: artificial lift methods, selection, Boolean logic, screening, efficiency

INTRODUCTION

At the beginning of the reservoir exploitation, the wells produce by natural flowing given the high initial energy of the reservoir. As this energy decreases, the pressure of the reservoir fluids become insufficient to ensure their upward flowing to the surface. Therefore, it is necessary to use an artificial lift method like gas lift, sucker rod pumps (SRP), electric submersible pumps (ESP), progressive cavity pumps (PCP), plunger lift, and hydraulic reciprocating pump (HRP) or hydraulic jet pump (HJP). These are the main or conventional methods used to lift the reservoir fluids to the surface. Each artificial lift method has the specific characteristics, advantages and disadvantages, and limits.

The right selection of these systems represents one of the most crucial steps in the developing of profitable exploitation of the reservoir. The physical-chemical properties of the reservoir and fluids, well type and trajectory, environmental circumstances, and economic reasons are considered when selecting the best artificial lift method. Also, an important aspect in the selection of an artificial lift system is related to the production cost that must be profitable even in the worst economic conditions, it being well known that the price of oil is very volatile (especially in the last two decades).

Therefore, the selection of the best artificial lift system is a complex process that implies multiple factors. The traditional methodology for choosing a suitable artificial lift method involves the process of establishing and analysing several criteria while taking into account the overall benefits and drawbacks of each method. Artificial lift method limits are continually shifting due to advancements in petroleum production technology, which has an impact on the circumstances under which they can be used.
Beside these methods, it was developed many methods based on the multi-criteria analysis and statistical data resulted from practice and specialized programs to select the best artificial lift method.

OVERVIEW OF ARTIFICIAL LIFT METHODS SELECTION

The conventional artificial lift systems are gas lift continuous (GLC) and gas lift intermittent (GLI), sucker rod pumps (SRP), electric submersible pumps (ESP), progressive cavity pumps (PCP), plunger lift, and hydraulic reciprocating pump (HRP) or hydraulic jet pump (HJP). These systems have specific characteristics and limits which are shown in the table 1.

Table 1. Main characteristic of artificial lift methods [13].

Operating Parameters	**SRP**	**ESP**	**HP**	**Gas Lift**	**PCP**	**Plunger Lift**
Typical depth (m)	300–3300	300–3000	1524–3050	3000	600–1400	2440
Typical flow rate (m^3/d)	0.8–240	30–3180	8-160	16-1590	0.8–350	0.2-1
Temperature (°C)	38–177	38–135	38-250	38–120	24–65	49
Corrosion handling	Good/ Excellent	Good	Excellent	Good/ Excellent	Fair	Excellent
Gas handling	Fair/ Good	Fair	Good	Excellent	Good	Excellent
Solids handling	Fair/ Good	Fair	Good	Good	Excellent	Fair
Fluid density (kg/m^3)	<1014	<1000	<1014	<966	<850	<966
Source of energy	Gas/ Electric	Electric	Electric	Gas	Electric	Fluid/ Gas
Offshore performance	-	Excellent	Excellent	Excellent	Good	-
Efficiency (%)	45-60	35-60	10-30	10-30	50-75	-

Further, we will present some aspects related to the operating principles, applications and some screening criteria that are critical for each conventional artificial lift systems. Therefore, the gas-lift system is applied in generally after the naturally flowing well ceasing to produce. Sometimes, this system can be used to improve the production of a naturally flowing well or to download a gas well. The gas lift system uses compressed gas that is injected through the annulus and passes through the gas lift valve (located at the bottom of the tubing) into the tubing string where it mixes with the reservoir fluids. Consequently, the fluid column weight drops and the bottom-hole flowing pressure allow to produce a flow rate that depends on the gas injection rate. The gas can be injected continuously or intermittently depending on the flow rate, bottom hole pressure, gas-oil ratio, and productivity index of the well. The completion of a gas-lift well is simple and is not limited by the well trajectory. Some authors [3][9] suggest a limit flow rate for continuous gas lift up to 24-32 m^3/day. Below these values of flow rate, intermittent gas lift should be applied. However, this limit of flow rate is pushed down in some oilfields. The main criteria used to screen the gas lift feasibility are related to the existence of the gas source, its capacity, maximum injection depth, flow rate, gas oil ratio, and bottom hole pressure.

Another artificial lift that uses the compressed gas or the energy of the gas accumulated in the annulus of the well is the plunger lift. The plunger lift is an intermittent artificial lift system where a freely moving plunger inside the tubing string lifts to the surface the liquid plug accumulated above it during the accumulation period. The plunger is activated by the compressed gas injected from the surface or by the energy of the gas accumulated in the annulus. After the injection period, the pressure into the tubing string and casing decreases and the plunger descends back by gravity to the bottom of the tubing string and the cycle starts again. The plunger lift system can be used as an intermittent gas lift or for gas well dewatering. Some specific criteria for this system are maximum liquid flow rates, pressure, and gas requirements.

The other artificial lift systems use different types of pumps activated by different types of energy (mechanic, electric or hydraulic) like progressing cavity pump, reciprocating piston pump, centrifugal pump, and hydraulic pump (reciprocating pump and jet pump). The PCP systems use a progressing cavity pump which is a rotary positive displacement pump. It has a simple configuration and is activated by the rod string which is rotated from the surface by a motor. Another variant of the PCP system uses a submersible electric motor to activate the pump. When the rotor is rotated within the stator, many opposites, identical and sealed cavities are created inside the pump along its entire length. These cavities are filled with fluids and are displaced from the intake to the discharge of the pump as the rotor is rotated within the stator. At the discharge, the pressure is enough to lift the fluids at the surface. The capacity of PCPs to manage solids, liquids, and gases is one of their key benefits, and also comparatively lower capital cost than other artificial lift systems [7]. The PCP system is used to produce oil and gas or to dewater gas wells and coalbed methane wells [7]. When we select this system is very important to check the pumping depth and the strength limits of the sucker rod string. Also, the number of rotations per minute must establish between 150-300 RPM [7].

In the case of the SRP system, the electric motor (most used) activates the pumping unit that transforms the rotational movement into translation movement which is transmitted to the sucker rod string and further to the piston within the cylinder of the pump. The piston pump is a reciprocating positive displacement type that uses the mechanical energy provided by the sucker rod string to lift the reservoir fluids to the surface. This system can be effective even at very low bottom hole pressure and flow rate if the intermittent variant is used. The main advantage is that it can produce in slim holes, multiple completions, high-temperature, and high viscosity oil[8] and has good efficiency(table 1).

The main disadvantage of the sucker rod pump is related to the presence of free gas that can temporarily block the pump. Consequently, it is necessary to check that the gas volume fraction is in the range of 0–40% [11], which is feasible for suction rod pumping.

ESP system uses a centrifugal pump which is activated by an electric submersible motor. It is best used in high-rate on- and offshore applications because they excel at lifting far greater liquid rates than most other types of artificial lift. On the other hand, this artificial lifting system has been adapted for low flow rates so that it can be an alternative to SRP or PCP.

Hydraulic pumping has proved good efficiency and impressive production rates (16-3180 m^3/d)[12]. The power is transmitted downhole by pressured power fluid flowing through the wellbore tubular. Hydraulic pump can be a reciprocating type or jet pump. Hydraulic reciprocating pump has a pair of coupled pistons, one of which is powered by the power fluid and the other of which pumps the well fluids. Hydraulic jet pump has no moving part which is a major advantage in comparison with the hydraulic reciprocating pump. The main components inside the pump consist of a nozzle, mixing tube or throat, and diffuser. The power pressured fluid is pumped from the surface. The potential energy of this is transformed in kinetic energy when it passes through the nozzle. In the throat, the energy of the power fluid is transferred to the reservoir fluids which enter the pump at the intake pressure. The power fluid and the reservoir fluids are mixed into the throat and have high kinetic energy when they arrive in the diffuser. Here, the kinetic energy is transformed into static pressure enough to lift the mixed fluids to the surface.

Hydraulic pumping usually works properly with wells that have holes that are crooked or deviated, which can be problematic for other kinds of artificial lift [12].

For the reciprocating hydraulic pump, it is necessary to avoid the wells with a high gas volume fraction, and for the jet pump, the conditions for the occurrence of the cavitation phenomenon must be checked. The maximum gas volume fraction recommended for these hydraulic pumps is 50%[11].

All the artificial lift systems presented above can be used also to dewatering gas wells. In figure 1 we show the efficiency of each conventional artificial lift system.

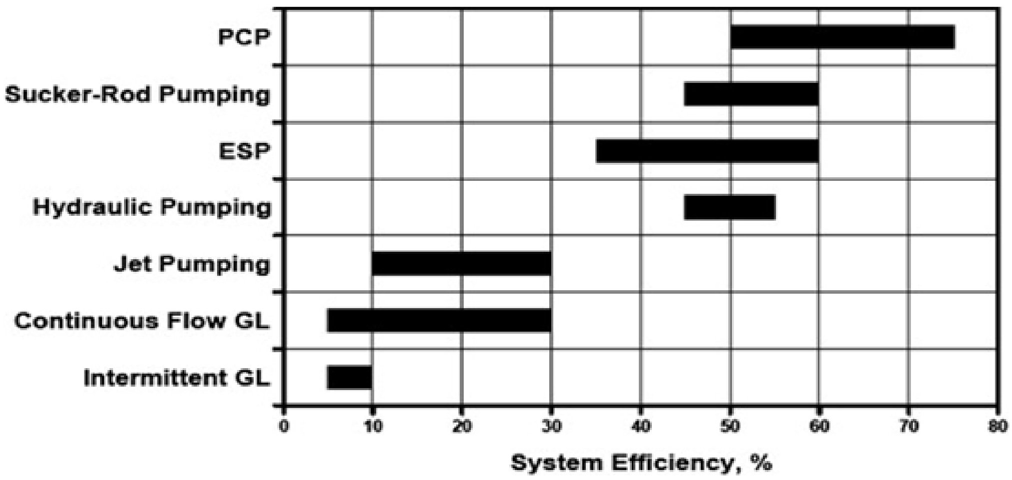

Figure 1. The efficiency of conventional artificial lift systems [8].

As we observe from figure 1, the PCP pump is the best artificial lifting device currently on the market. The PCP systems are the most effective artificial lift solutions because they need one of the simplest surface and downhole installations and have the lowest energy losses in system components. The PCP system is followed by the SRP system and the ESP system with a maximum efficiency of about 60%.

Hydraulic piston pumping installations have a power efficiency of around 50% while hydraulic jet pumping performs with a maximum of 30%. Gas lift is also performing with similar efficiency as hydraulic jet pumping, but when it is used intermittently has the lowest energy efficiency among all, roughly 10%.

The selection of an artificial lift system can be achieved by many methods such as using the charts of the depth/rate capabilities [12], using the comparison between the advantages and disadvantages of the artificial lift systems [3], using a decision tree[5], using economic analysis[12] and using the expert programs such as OPUS, SEDLA[10][4] and optimization model such TOPSIS [1]

Therefore, Clegg et al.[3] provide large attribute tables with many details regarding the main artificial lift systems which are very useful in the screening process.

Chow et al.[2] provide a semi-automatic screening tool for artificial lifting systems which allows a quick selection of these. The selected artificial lift systems will be further investigated. The method has three steps determining technical viability, answering well-specific questions, and ranking the artificial lift systems.

Heinze et al.[5] propose a simple method for the selection of an artificial lift system based on the decision tree. This method has three: steps1. reducing the possibilities based on checking the critical limits, 2. checking the second limitations related to the temperature limitations, operational personal training, availability of power source, surface considerations, and additional downhole limitations, and 3. economics analysis. This method provides the best artificial lift system for specific input data.

The expert programs are the most complex including different modules. For example, the Espin et al.[4] developed the expert program named SELDA(Sistema Experto de Levantamiento Artificial) which has three modules of ranking the artificial lift systems, simulating the design, and economic evaluation. Also, Valentin et al.[10] developed an expert program (OPUS- Optimal Pumping Unit Search) based on artificial intelligence technology combined with algorithmic techniques.

Alemi et al.[1] proposes an optimization method for the selection of artificial lifting systems based on the TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) model that searches for the optimal solution based on the shortest Euclidean distance from the ideal solution and the furthest from the negative ideal solution.

BRIEF DESCRIPTION OF THE MODEL DEVELOPMENT

The model was developed using the Boolean logic. The three terms "Or," "And," and "Not" serve as the core of the algebraic concept known as Boolean logic, the founding principle is that any value can only be either true or false. Application of the Boolean logic scheme enables a comparison of parameters for the optimization criteria using multiple vectors to store the limits of the set of parameters used as a decision-making tool. The model is written in Visual Studio 2022 using the programming code C#. Each and every selected parameter for choosing the artificial lift can be measured before the reservoir runs out of energy and one of these systems is needed. Those parameters are obtained from the drilling process, reservoir properties, and from the natural flow production.

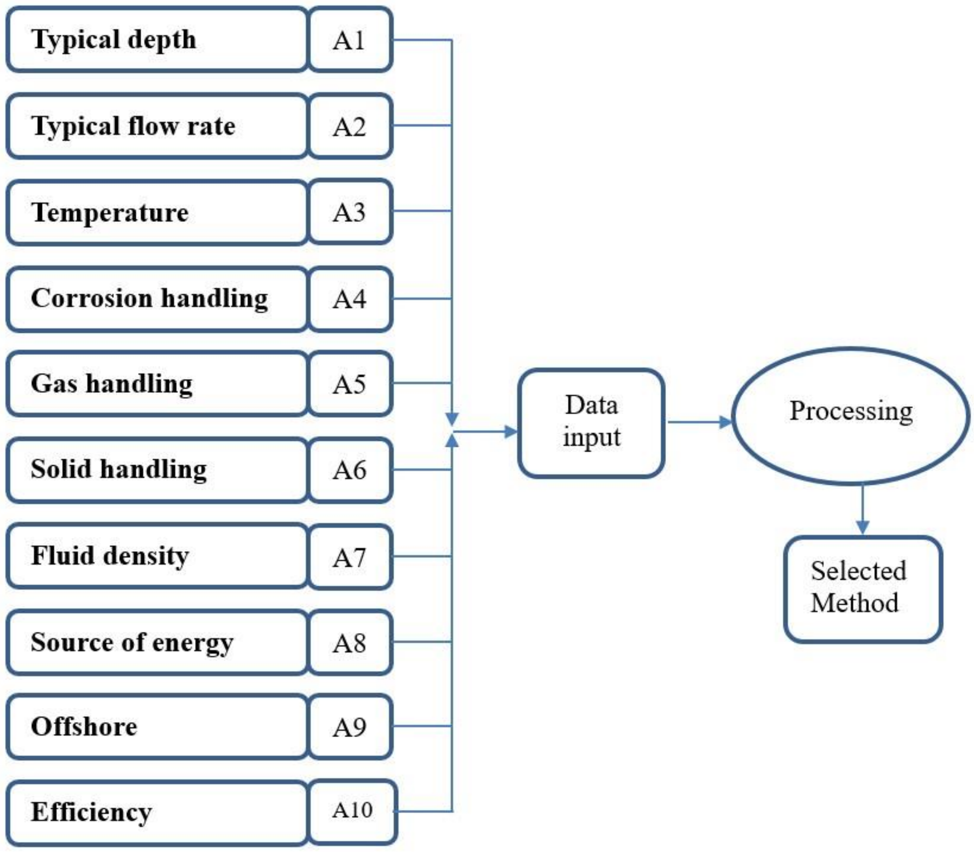

Figure 2. Scheme of the model.

As we show in the Figure 2, the parameters considered to be defining for the selection of the best artificial lifting method are numbered from A1 to A10 and include physical-geological parameters (depth, fluids flow rate, temperature, fluid density), production problems (corrosion, solid particles, gas), and applicability (source of energy, offshore performance, efficiency).

Each of these parameters has its own characteristics and limitations specific to one of the seven artificial lift methods analysed. Their values are taken from the experience of production engineers and are used as a reference.

Assuming we have all the attributes filled in with real values, they are encrypted into the main selection algorithm based on having a list of wells that works like a memory database. The algorithm goes through each entity in this list and compares each attribute with the one entered by the user. The algorithm creates a score for each type of well completion and sends the user to the next window. We can afford to use this type of approach only because we have seven types of artificial lift.

The operating parameters are encrypted as vectors ranging from two defined values displayed in Table 1. In order to obtain a "point" the data introduced by the user must be somewhere between those values, as for the drawdown sections the program relies exclusively on the user input.

There are few isolated cases where the program could not count some of the drawdowns but in those cases, the user had introduced invalid data. There will not exist any loopholes if the data is valid even though in some cases the program might score the same two or more artificial lift methods.

In case, we have more than one well with the same score, we use the efficiency field (optional to fill in, specified above) to distinguish the best result, the efficiency of each artificial lift type is known based on previous experiences. For the situation when the score is the same for two or more methods and the user did not fill in the optional field, the program will automatically compare the worst scenario, when the artificial lift has the minimum performance and choose it by itself.

If there is a user that will not enter real data from the field, a red text message will appear below "Efficiency" asking the user to check the input values. After pressing the submit button, the model will process the data and will display a secondary window containing a picture of the artificial lift method.

Besides the picture of the artificial lift technique illustrated and its particular equipment, there will be also displayed two tables with the most important and frequent advantages and disadvantages. The information has been obtained from reference [3] and resembles real-life conclusions due to the problems and challenges from the field experiences.

These aspects side to side will create an overview and will lead to further investigation therefore completion engineering can start preparing future equipment needed for continuous production.

Phase 1 is creating a list of "Oil Wells" where the characteristics of each artificial lift system will be introduced.

```
private List<OilWell> Sonde = new List<OilWell>();
    private UserConfiguredOilWell Well { get; set; }
    private OilClassifierService Classifier;
    public Form1()
    {
      InitializeComponent();
      if (Sonde.Count == 0)
      {
        AddOilWells();
      }
    }
    private void AddOilWells()
    {
      OilWell s1 = new OilWell
      {
        Id = 1,
        Name = "Gas Lift",
```

```
        FixedDepth = 3000,
        DepthMin = null,
        DepthMax = null,
        DebitMin = 16,
        DebitMax = 1590,
        FixedTemperature = null,
        TemperatureMin = 38,
        TemperatureMax = 120,
        Corosion = "Good/Excellent",
        IsGas = "Excellent",
        IsSolid = "Good",
        FluidDensityMin = 0,
        FluidDensityMax = 966,
        EnergySource = "Compressor",
        Offshore = "Excellent",
        EfficiencyMin = 10,
        EfficiencyMax = 30
    };
```

Phase 2 is creating an interface with details where the user will introduce the data and also a place where the information is temporarily saved.

```
private void textBox1_Enter(object sender, EventArgs e)
    {
        label12.Text = "";
        if (textBox1.Text == "m")
        {
            textBox1.Text = "";
            textBox1.ForeColor = Color.Black;
        }
    }

    private void textBox1_Leave(object sender, EventArgs e)
    {
        if (textBox1.Text == "")
        {
            textBox1.Text = "m";
            textBox1.ForeColor = Color.DarkGray;
        }
    }
```

Phase 3 consists of processing the data and creating a score, the parameters introduced are compared to each range of that parameter values specific to every artificial lift system. After analyzing the parameters, the algorithm will raise the value with 1 point for the ones who fit the required condition. This process is done seven times for every artificial lift technique, the one with the highest score will be chosen. Example for checking the depth:

```
private bool CheckDepth(int pos)
    {
        if (OilWells[pos].FixedDepth != null)
        {
            if (OilWells[pos].FixedDepth == OilWell.Depth)
            {
                return true;
            }
        }
        else
        {
            if (OilWell.Depth >= OilWells[pos].DepthMin && OilWell.Depth <=
OilWells[pos].DepthMax)
            {
                return true;
            }
        }
        return false;
                                                }

int maxScore = 0;
        int bestResultId = 0;
        double maxEfficiency = 0;
        for(int i=1;i<=7;i++)
        {
            if(score[i] > maxScore)
            {
                maxScore = score[i];
            }
        }
        for(int i=1;i<=7;i++)
        {
            if(score[i] == maxScore)
            {
                if(OilWells[i-1].EfficiencyMin > maxEfficiency)
                {
                    maxEfficiency = OilWells[i - 1].EfficiencyMin;
                    bestResultId = i;
                }
            }
        }
                                    return bestResultId;
```

Phase 4 displays the result of the counting together with its advantages and disadvantages (figure 3). This is a pure example set of data to show how the program works.

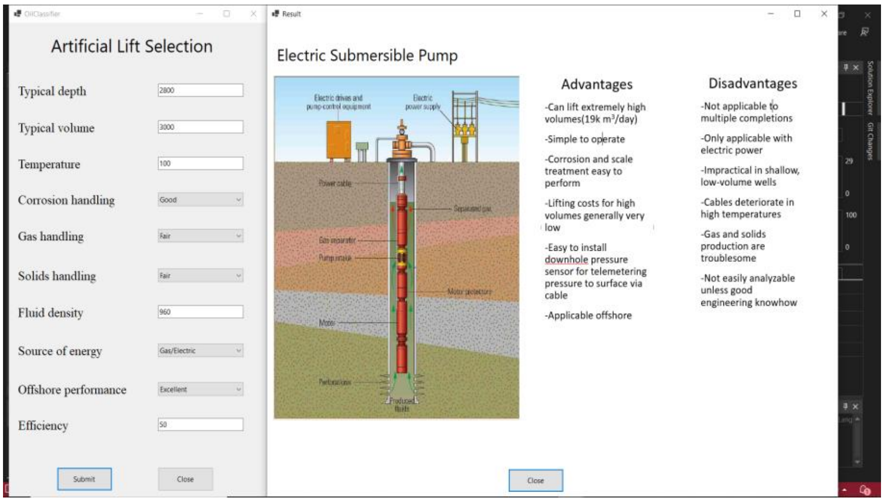

Figure 3. Visual Studio display - example

RESULT AND DISSCUSION

To test the real-life efficiency of the algorithm we collected two sets of data from two different fields where the artificial lift methods are already applied. These pieces of information were measured right before applying the technique. We expect to have identical approaches so that the program is viable. In the field, for Well 1 there has been applied the PCP and for Well 2 has been applied the SRP. After running the program with the data prelevated from the two wells, it resulted that the algorithm has chosen the same methods and there are in the field and they proved to be the most efficient ones. In figure 4 and figure 5 there are displayed the results of the running.

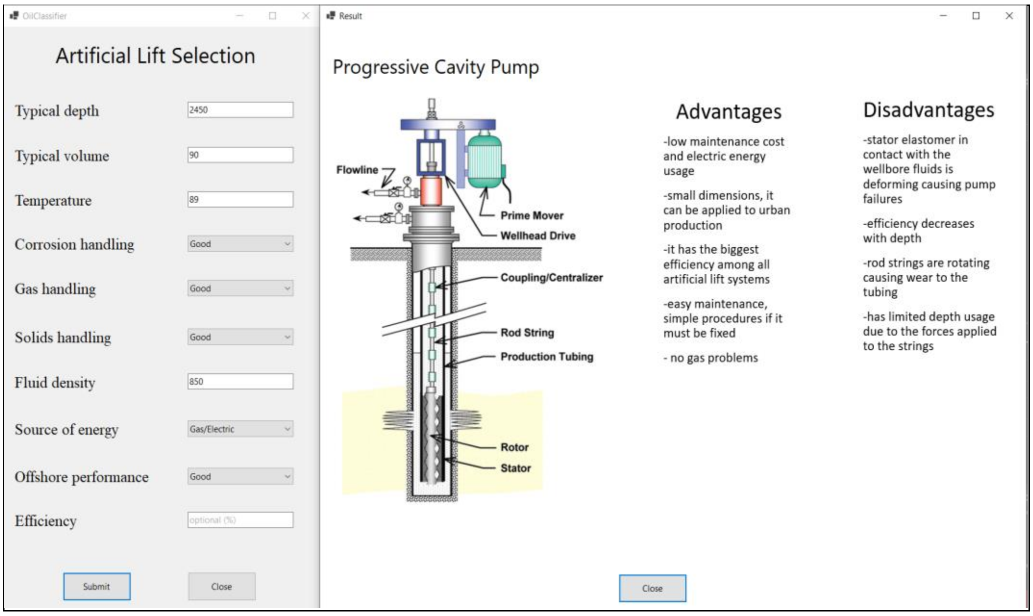

Figure 4. Visual Studio display-Well 1

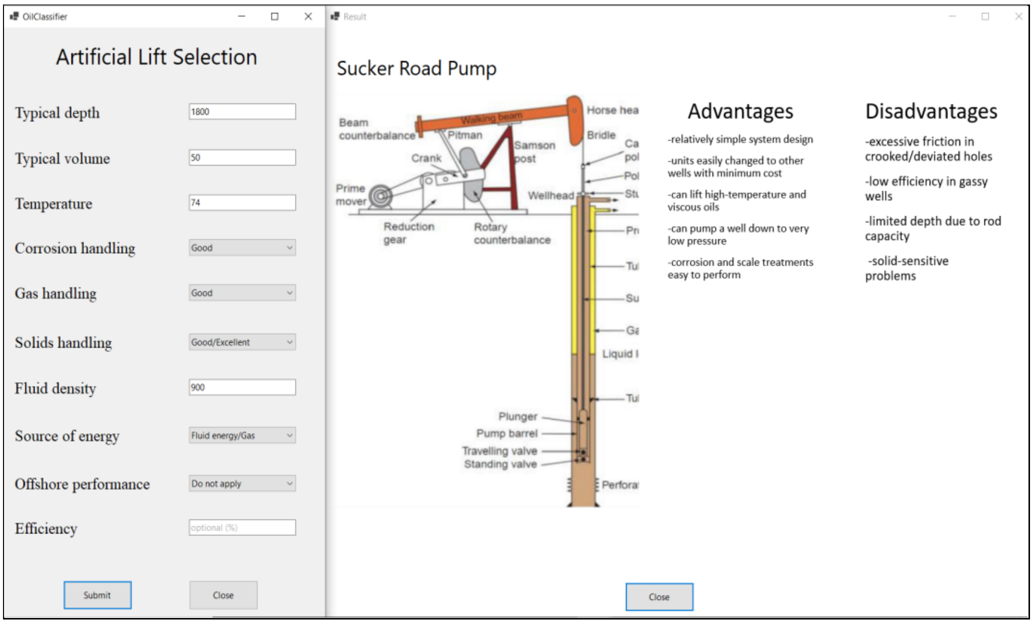

Figure 5. Visual Studio display-Well 2

CONCLUSION

The selection of an artificial lifting system has important effects on the profitable exploitation of an oil field in the long term. An improper selection of these systems can lead to lower production and increased operating costs.

The process of selecting is closely related to the way the oil reservoir is exploited. This process has three stages: screening, forecasting, and selection. During the screening phase, artificial lift systems are evaluated and ranked according to the conditions specific to the field and the operating environment.

The model aims to combine these three stages so it will speed up the process of choosing and maximize the economic aspects. Oil prices being so volatile makes it very hard to determine if a well will be a profitable long-term investment. As a future work that has to be done is to improve the algorithm by adding more parameters, several criteria for a accurate selection, also contain an economic module.

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