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PHYSIOLOGICAL ASPECTS OF HIGH-TECH REFINERY OPERATORS' WORK

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ФИЗИОЛОГИЧЕСКИЕ АСПЕКТЫ РАБОТОСПОСОБНОСТИ ОПЕРАТОРОВ ВЫСОКОТЕХНОЛОГИЧНОГО НЕФТЕПЕРЕРАБАТЫВАЮЩЕГО ПРОИЗВОДСТВА

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Work at high-tech refineries is characterized by such the main factors as complexity of workers' duties (pace, nature of mental tasks), intense static and dynamic loads, irrational work regime.

It is known that the decrease in work efficiency is the result of the influence of factors of the labor process (the monotony of external stimuli, long stay in the required working position, restriction of physical activity, relative isolation and sensory insufficiency). That is caused by the development of inhibition in the cerebral cortex and weakening of excitatory process. Arrival of the signal expected is associated with the transition to intensive activities at the control panel according to a specific algorithm or the operator's labor intensity in the long standby mode.

The paper presents results of studies of the basic physiological parameters of the respiratory and cardiovascular systems of operators during 12-hour work shifts. The assessment confirmed the high "physiological cost" of the operators' work activity, myocardial hypoxia observed in the work shift process, reduced mental performance, development of fatigue, therefore, conditions for reducing the reaction rate and possible error actions of the staff in this work process organization.

In addition, the probability of provoking negative changes in the health of operators and possibility of developing a number of cardiovascular diseases, including those caused by production activities, have been confirmed.

There is a need to develop individual strategies to adapt to the labor process, taking into account age and professional features of the activity, as well as the development of rational shift regimes of work and rest for working on 12-hour work schedules taking into account the regular changes in the phase character of working capacity in order to optimize conditions and increase productivity.

Ключевые слова:

работоспособность операторов, синдром монотонии, внутрисменное утомление, умственное напряжение, «физиологическая цена» трудовой деятельности, гипоксия, астения донозологического характера.

К основным факторам деятельности операторов высокотехнологичных нефтеперерабатывающих производств относятся: сложность выполняемой человеком работы (темп, характер мыслительных задач); напряженные статические и динамические нагрузки, нерациональный режим труда.

Известно, что снижение работоспособности является результатом воздействия факторов трудового процесса (монотонность внешних раздражителей, продолжительное пребывание в вынужденной рабочей позе, ограничение двигательной активности, относительная изоляция и сенсорная недостаточность), в основе чего лежит развитие торможения в коре больших полушарий и ослабление возбудительного процесса. Поступление ожидаемого сигнала связано с переходом к интенсивной деятельности за пультом управления по определенному алгоритму или напряженностью труда оператора в режиме длительного ожидания.

В работе представлены результаты выполненных исследований основных физиологических параметров дыхательной и сердечно-сосудистой систем операторов в процессе 12-часовых рабочих смен. Выполненная оценка подтвердила высокую «физиологическую цену» трудовой деятельности операторов, наблюдаемую в процессе рабочих смен гипоксию миокарда, снижение умственной работоспособности, развитие утомления, следовательно, условия для снижения скорости реакции и возможной ошибочности действий персонала при настоящей организации трудового процесса имеются.

Кроме того, подтверждена вероятность провоцирования негативных изменений здоровья операторов и возможность развития ряда сердечно-сосудистых заболеваний, обусловленных в том числе и производственной деятельностью.

Имеется необходимость разработки индивидуальных стратегий адаптации к трудовому процессу с учетом возрастных и профессиональных особенностей деятельности, а также разработки рациональных внутрисменных режимов труда и отдыха для работающих по 12-часовым рабочим графикам с учетом закономерных изменений фазовости работоспособности с целью оптимизации условий и роста производительности труда.

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Introduction

The value of operator's job in various areas of professional activity increases constantly. A man's role in the management of technological processes does not decrease, but becomes of great importance [1-6]. Studies show that while performing operator's duties against the background of intense mental activity, high level of professional responsibility for possible erroneous actions personnel suffers monotony and hypokinesia [3, 6-12]. Another important feature of the operator's job should be noted. That is work in a continuous standby mode, which complicates the above-mentioned employee conditions. Transition to 12-hour shifts enhances the development of intra-shift fatigue [13-17].

Due to the mentioned above, research on the problem of mental performance in various conditions of professional activity remains relevant [3, 18-21].

Fatigue that develops among operators should be considered as a physiological state after intensive and prolonged labor mobilization of the body. [22, 23]. However, the special role of operator's work is associated with the need to minimize possible erroneous actions, since it has been proven that against the background of fatigue, the number of errors increase [24-27]. In some studies, this type of fatigue is diagnosed as asthenia of a prenosological or reactive nature, which occurs after excessive mental or mental stress, in violation of work and rest, systematic lack of sleep, adaptation to new climatic conditions etc. In papers that state is called informational neurosis, manager syndrome, white-collar syndrome [2, 28-30].

It is known that acute oxygen starvation is an attribute of intense mental work, so the more functional elements in the processing system of spatial, visual, verbal information, the less effective it will be under the conditions of hypoxia. In connection with the foregoing, the energy deficit in brain cells and cardiovascular system, created by intense mental work, will affect the mental work ability of operators, since it is known

that acute oxygen starvation contributes to intense mental work [3, 7, 29, 31, 32].

In the general system of intellectual functioning running memory is the key and most sensitive component that determines the effectiveness of professional activity [33, 34]. At the same time, there is no attention paid to the study of mechanisms of the performance dynamics and the error-free operator's actions [3, 24, 35].

The purpose of this study is to assess the operator's work ability using informative physiological parameters and to justify possible ways to prevent fatigue of workers.

Research data and methods

The studies were performed at a large industrial enterprise during 12-hour working shifts with the participation of the operators of the main control panel. Studies were conducted in groups of operators and shift supervisors, in total 60 people took part.

During the assessment of physiological parameters of the body in the dynamics of work shifts blood saturation was determined by the method of pulse oximetry, lung capacity, blood pressure, heart rate, dynamometry, blood circulation efficiency (BCE) and double multiplication – the Robinson index (IR) were calculated.

Pulse oximetry was performed during determination of one of the main indicators of the normal functioning of the body (saturation of arterial blood with oxygen). The measurement of this indicator was performed on equipment of the MD300C series: MD300C2.

Pulse oximetry allows to determine the concentration of oxygen in arterial blood and pulse rate. The norm saturation is the same for adults and is equal to 95-98 %.

Determination of this parameter has some peculiarities related to the fact that the blood of an adult, in addition to restored hemoglobin and oxyhemoglobin, contains at least two more types of hemoglobin that are not involved in oxygen transport: methemoglobin (MetHb) and carboxy-hemoglobin (COBb). Excluding pathological

conditions, these fractions are contained in the blood in fairly low concentrations: MetHb – 0.2-0.6 %, COHb – 0-0.8%. Overload hypoxia is physiological and can develop with intense mental work, when cells vigorously consume oxygen. Most likely, this phenomenon can be attributed not to the state, but to the symptom of a temporary decrease in the oxygen content in the body in the process of intense mental labor. Therefore, the control of oxygen content can be used as an indicator of the dynamics of fatigue during labor shifts [25, 29, 36].

Indirectly, the moment when hypoxia occurs is confirmed by calculated indicators, which are used by us for a visual objective assessment based on the results of a physiological survey of workers during labor shifts. The BCE and Robinson index (double multiplication) are between the indicators. Basically, the BCE is essentially a minute volume of blood, which normally is 2,600 ml/min and increases with fatigue. The calculation of the indicator, ml/min, is carried out according to the formula

$$\text{BCE} = (\text{SP} - \text{DP}) \text{ bpm},$$

where SP – systolic blood pressure value, mm Hg; DP – diastolic blood pressure, mm Hg.

Robinson Index (or double multiplication, DM), cond. units, as an indicator characterizing the mechanical activity of the heart and blood circulation apparatus as a whole, indirectly indicates the consumption of oxygen by the myocardium and is calculated by the formula

$$\text{DM} = (\text{SP} \cdot \text{HR}) / 100,$$

where SP – systolic blood pressure value, mm Hg; HR – heart rate for 1 minute, min^{-1} . Criteria for the indirect evaluation of a double product are average values – from 76 to 89 cond. units; above average – 75 and less; below average – 90 and above.

Results and discussion

Study results are presented in the table. Estimation of the vital capacity of the lung (VC) among operators of different departments showed that deviations from the proper VC are within

$\pm 3-7$ %. Therefore, these values can be regarded as a normal value, since the reduction of VC to 80 % of the proper value should be considered physiologically significant.

The state of fatigue of workers can be established by a number of physiological indicators of the activity of the cardiovascular and respiratory systems, and the calculation of the BCE and Robinson index allows visual presentation of the results. Usually it is 86.8 ± 15 . The smaller the Robinson index, the higher the limiting aerobic potencies and the level of the individual's somatic health. In terms of the age it does not undergo noticeable changes, as the HR decreases with age, and the SD increases.

Analysis of the values of the Robinson index in the table showed that oxygen consumption by the myocardium during the work activity of the operators undergoes adverse changes. It was noted that even at the beginning of day and night shifts oxygen consumption by the myocardium is below the average normal level; there is an intensive subsequent decrease in this indicator by the end of 12-hour work shifts. Perhaps this phenomenon is associated with the action of the identified syndromes of monotony and hypokinesia that accompany the work of the operators.

Consequently, the calculation of the Robinson index in the studied contingent of workers showed indirectly the presence of conditions for the formation of a symptom of chronic hypoxia. That may ultimately indicate adverse changes in the cardiovascular system and indicate in the long run a possible provocation of the development of chronic pathology [2].

The calculation performed indicates that normal values of BCE are 1.5-2.0 times larger during the day and night shifts. Therefore, fatigue accompanying the hard work of operators is so great at the very beginning of work shift and during the activity, which can lead to an increase in erroneous actions. Earlier we noted that requirements to results of occupational duties became stricter. That leads to a particular intensive stress and overstrain of workers' body and indicates a high "physiological price" of this work [13, 14, 37].

Physiological indicators of operators during work shifts and shift supervisors during the labour

Division	Shift	Shift period	Blood saturation oxygen		Lung capacity, l	Arterial pressure	Robinson index, ml/min	BCE	Pulse, bpm	Dynamometer, N
			before walk	after walk						
<i>Operators</i>										
ORD	Daytime	Beginning	98	99	4.23 (standard \pm 5 %)	153/86	108.63	4,970	71	48
		End	98	99	4.43 (standard \pm 3 %)	139/81	91.74	3,828	66	48
	Night	Beginning	98	99	4.6 (standard \pm 3 %)	135/80	94.5	3,850	70	46
		End	98	100	4.83 (standard \pm 6 %)	132/76	88.44	3,752	67	47
PIRD	Daytime	Beginning	98	100	4.75 (standard \pm 5 %)	135/76	87.75	3,835	65	51
		End	98	100	4.36 (standard \pm 4 %)	133/76	91.77	3,933	69	52
	Night	Beginning	98	100	4.87 (standard \pm 6 %)	130/70	85.8	3,960	66	50
		End	98	100	4.77 (standard \pm 5 %)	127/67	80.01	3,780	63	51
<i>Supervisors</i>										
ORD	Daytime	Beginning	97	100	3.71 (standard \pm 18 %)	134/81	95.14	3,710	71	52
		End	98	100	4.25 (standard \pm 5 %)	133/81	95.76	3,744	72	53
	Night	Beginning	97	99	4.2 (standard \pm 6 %)	129/76	90.3	3,710	70	49
		End	99	100	4.46 (standard \pm 3 %)	145/82	94.25	4,095	65	49
PIRD	Daytime	Beginning	96	99	4.48 (standard \pm 3 %)	116/75	84.68	2,993	73	49
		End	97	99	3.82 (standard \pm 16 %)	117/74	91.26	3,096	78	50
	Night	Beginning	97	99	4.37 (standard \pm 4 %)	128/70	92.16	4,176	72	50
		End	98	100	4.11 (standard \pm 7 %)	130/70	97.5	4,500	75	49

Note: ORD – oil refining division; PIRD – primary oil refining division.

The identified changes in working capacity were confirmed by results of physiological studies and showed a decrease in the speed of visual-hearing and motor signal differentiation and an increase in the number of erroneous actions of operators by the end of the work shift [14, 37].

Methods of processing spatial and verbal information, involve more links (actions) and more difficult way to obtain the desired result. Therefore, hypoxia, like a tiring cognitive load, has a more intensive negative effect on mental performance indicators [1, 19, 27, 36, 38]. Consequently, hypoxia in the studied contingent of

operators should be regarded as a possible cause of the erroneousness of actions.

In terms of dynamics of the physiological reactions of the body of the shift supervisors the results obtained can be correlated mostly with people of 50 years old. Despite the overall fairly stable picture of the physiological indicators of the cardiovascular and respiratory systems, the design parameters allow to objectively present and evaluate it. Thus, the Robinson index showed that the activity of the cardiovascular system of workers takes place under conditions of oxygen deficiency (hypoxia). This

phenomenon is observed in both day and night shifts, and myocardial hypoxia is detected at the beginning of work shift. Therefore, this contingent workers present a symptom of chronic hypoxia. No particular differences related to the age of the examined were revealed at this stage of the research. The BCE among shift supervisors increases during the shift by 1-7 % of the initial value, which indicates body fatigue at the beginning and during the labor. Nevertheless, the intensity of fatigue is much lower than the operators of shift managers. It is supposed that this is caused by adaptation of the organism to the conditions of work, accumulation of experience, possible use of individual methods of preparing for a shift (including inter-shift and pre-shift rest).

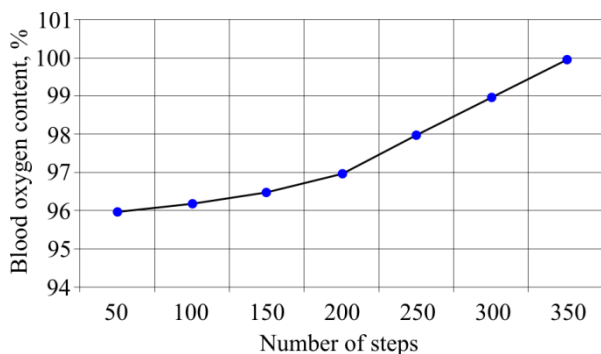


Fig. Oxygen content in peripheral blood depending on the number of steps during a walk

It is worth saying, that actual and must be VC of the shift supervisors are different. Deviations from the proper values range from 3 to 18 %. Probably, the indicator plays a certain role in myocardial hypoxia development. A walk in the air should be considered as one of the ways to prevent fatigue, improve performance and

oxygenation of blood. We carried out a study of blood saturation during walks with a given number of steps. It was established that in all subjects the blood saturation with oxygen up to 100 % occurred when moving up to 350 steps, and this condition was achieved in 6 minutes of walking (Fig.).

Results

The studies carried out confirmed the high “physiological price” of the operators’ work activity, hypoxia of the myocardium observed during the work shifts, reduced mental performance, and development of fatigue. Therefore, there are conditions for reducing the reaction rate and possible erroneous actions of the personnel.

Thus, the readiness of the body to perform the responsible hard work of the operator of a high-tech enterprise, the state of the body during labor shifts do not meet the required parameters and may cause errors in the performance of direct professional duties.

In addition, the probability of provoking negative changes in the health of operators and the possibility of developing the number of cardiovascular diseases, including those caused by production, have been confirmed.

There is a need to develop individual strategies to adapt to the labor process, taking into account age and professional features of the activity.

The studies carried out indicate the need to develop rational internal shift modes of work and rest for an operator that work for 12 hours. Regular changes in the phase of working capacity have to be considered in order to optimize conditions and increase productivity.

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